AD ____________________

MIPR NUMBER 95MM5559

TITLE: Neck and Back Strain Profiles of Rotary-Wing Female Pilots

PRINCIPAL INVESTIGATOR: James A. Hodgdon, Ph.D.; Robert S. Pozos, Ph.D.; Steven J. Feith, CDR, MSC, USN; Barry S. Cohen, LT, MSC, USNR

CONTRACTING ORGANIZATION: Naval Health Research Center
San Diego, California 92138

REPORT DATE: March 1997

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1997	Final (8 Dec 94 - 30 Apr 96)

4. TITLE AND SUBTITLE
Neck and Back Strain Profiles of Rotary-Wing Female Pilots

5. FUNDING NUMBERS
95MM5559

6. AUTHOR(S)
Hodgdon, James A., Ph.D.; Pozos, Robert S., Ph.D.;
Feith, Steven J., CDR, MSC, USN; Cohen, Barry S., LT, MSC, USNR

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center
San Diego, California 92138

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)* The research objectives of this study were to: 1) assess the prevalence of neck and back symptoms in Navy helicopter aviators; 2) determine the magnitude of strain in neck and back muscles using electromyogram (EMG) signals associated with muscle contractions before, during, and after helicopter flights; 3) minimize neck and back fatigue during flight using specific neck and back strengthening exercises; 4) quantify the effect of various helmets with and without accessories (i.e., night vision goggles) in promoting neck/back strain both during actual and simulated flights; and 5) predict neck and back fatigue from a model of biomechanical variables. Using surface EMGs and video data, in-flight muscle activity and head-movement were quantified. The small number of subjects precluded comparisons between genders. Analysis of EMG suggested fatigue in the neck muscles during flight, but not in the back. Physical training with MedX equipment resulted in an increase in cervical rotation strength and time to fatigue during back extension. Limited studies were conducted on a jolt impact platform. Vibratory patterns on this simulator did not mimic in-flight vibration patterns, and the data collected were not used. These studies need to be replicated. A model predicting forces generated by helmet loading was developed.

14. SUBJECT TERMS Defense Women's Health Research Program
Cervical and back exercise, fatigue, cervical injury, soft-tissue injury, cervical pain, anthropometry, human subjects, electromyography (EMG), spectral analysis

15. NUMBER OF PAGES
58

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the US Army.

✓ Where copyrighted material is quoted, permission has been obtained to use such material.

✓ Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

✓ Citations of commercial organizations and trade names in this report do not constitute an official Department of Army endorsement or approval of the products or services of these organizations.

N/A In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Resources, National Research Council (NIH Publication No., 86-23, Revised 1985).

✓ For the protection of human subjects, the investigator(s) adhered to policies of applicable Federal Law 45 CFR 46.

N/A In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to the current guidelines promulgated by the National Institutes of Health.

N/A In the conduct of research utilizing recombinant DNA, the investigator(s) adhered to the NIH Guidelines for Research Involving Recombinant DNA Molecules.

N/A In the conduct of research involving hazardous organisms, the investigator(s) adhered to the CDC-NIH Guide for Biosafety in Microbiological and Biomedical Laboratories.

PI - Signature 3/20/97
Date

TABLE OF CONTENTS

INTRODUCTION

Helicopter pilots experience both acute and chronic back pain that is associated with flight operations. Shanahan et al. (1985) found that 50% of the helicopter pilots they studied reported transient pain associated with flights (1). The pain was described as a dull ache, localized in the lower back and lasting less than 24 hr. This transient pain may be a precursor to the development of chronic back pain, other back disorders, and ultimately, disability (2). The back pain may result from poor posture, cockpit ergonomics, vibration of the aircraft during flight, or flight hours. Chronic back pain also may be related to the total number of flight hours, since it is associated with the accumulation of between 1400 and 2400 flying hr (3,4). In addition, helicopter pilots have four times the incidence of vertebral disorder spondylolisthesis of cadets or transport pilots (5).

The paraspinal muscles exhibit tonic activity while the helicopter pilot is flying the aircraft. It is postulated that these continuous contractions could lead to compression of the vertebral disks and contribute to the development of back pain. It has been suggested that fatigue of these paraspinal muscles may manifest itself as lower back pain, rather than as force diminution seen with normal muscle fatigue protocols (6). Evidence of paraspinal fatigue during helicopter operations is based on both increased subjective fatigue response, using visual analog scales, and a decreased central power frequency in the electrical activity of the muscles, or electromyogram (EMG) (6,7).

The helicopter community has documented a number of occupational ailments attributable to external forces, including: (1) cockpit ergonomics, (2) helmet mass and design, (3) peripherals on the helmet, (4) muscle fatigue, and (5) repeated jolt impact, resulting from airframe vibration, leading to soft-tissue injury (8). These disorders occur primarily in the neck, lumbar, and upper sacral regions (9). However, the majority of available information on these disorders was collected on male pilots. In a recent study of neck and back disorders in combat aviators, only 2 of 60 subjects studied were females (8). The results obtained in males are unlikely to generalize to females because of anthropometric differences.

With an increasing number of females serving in the military, the number assigned to helicopter squadrons is expected to increase. Physical performance studies show that, in general, females have greater flexibility and less strength than males (10). Anecdotal evidence from civilian automobile accidents suggest that female victims suffer more chronic neck and back injury than males. These injuries may be due in part to the differences in strength and flexibility. Overall, the combination of less strength and more flexibility could increase the likelihood of neck and back pain and injury in female pilots.

To address issues associated with the increasing number of female pilots in flight operations, the Navy initiated the Amelia program. Pokorski surveyed 343 female aviators to determine their unique equipment requirements for flight operations (9). The most frequently reported problem was the design and weight of the helmet. It has been reported that the helmet contributes significantly to neck and back fatigue for male pilots (11) and the fatigue effects of the helmet appear to be enhanced by vibration of the helicopter airframe (4). Currently, there are no comparable data on female pilots, however, the potential for even greater effects exists. The onset of fatigue and associated problems could result in decreased effectiveness and if the problems are severe, may result in permanent loss of flight status for these highly trained personnel. Chronic in-flight vibration may be an additional causative agent in soft-tissue injury to pilots. The effects of repeated vibration and jolt impact stress, and the weight of the helmet may additively or synergistically cause fatigue of the neck and back muscles in helicopter pilots (12).

In addition to helmet weight and airframe vibration increasing neck and back fatigue, air combat maneuvers (ACMs) act as G-force stressors on the aircrew. Although a number of studies have examined the effects of ACMs on neck function with different helmets and mask configurations, no standardized experimental methodology has been developed to assess the degree of injury risk posed by head and helmet mounted systems (13).

Previous studies have indicated that a decrease in frequency and an increase in amplitude of the activity of EMG is correlated with fatigue (14,15,16). EMG methodology records and analyzes complex electrical signals associated with muscle contraction (17). The frequency and amplitude characteristics of the EMG are determined by various patterns of motor unit activation (18). More recent investigations have quantified changes in the components of the EMG waveform as the muscle fatigued during concentric and eccentric contractions (19). The use of EMG to quantify pilots' neck and back muscle fatigue during flight could provide valuable insight into the origin of the associated pain.

This technology was used recently (20) to examine neck and back fatigue in female and male Navy pilots exercising to strengthen specific muscle groups. EMGs of male Navy pilots exercising to fatigue were analyzed using a "moving window" spectral technique. The analyses indicated that, as muscles fatigue, there was an increase in EMG amplitude (root mean square [RMS]) and a decrease in mean power frequency (MPF). In some subjects, the RMS values decreased before the subject fatigued, indicating that other muscle groups were being recruited and that the decrease in the isolated RMS value of single muscle groups may be an early indicator of fatigue (20). These studies also indicated that increasing recruitment of lumbar musculature was associated with neck muscle fatigue. It was hypothesized that neck fatigue, triggering increased lumbar muscle activity, may be a predisposing factor in low-back pain in Navy pilots (Pozos, R.S., unpublished data, 1995). Evaluation of neck and back function using EMGs and force measurement on MedX equipment, indicates that the neck and back muscles do not fire (contract) bilaterally to the same degree. A functional bilateral asymmetry exists between the right and left neck and back muscles during extension and flexion, a factor that may predispose an individual to fatigue, lead to soft-tissue injury, and in extreme conditions, permanent alteration of neck and back vertebral column or musculature.

Until recently, recording in-flight EMGs was not possible. With the recent development of a small recorder and battery-driven amplifier, the capability now exists to record four muscle groups simultaneously during flight maneuvers. The Naval Health Research Center (NAVHLTHRSCHCEN) has further developed the capability of recording surface EMGs with simultaneous recording of video images (21,22). The advent of a small video camera synchronized with the portable EMG system allows the simultaneous recording of both head movement (displacement, velocity, and acceleration) and EMGs. Using this solid-state technology, NAVHLTHRSCHCEN conducted laboratory and in-flight studies in fixed-wing aircraft and helicopters, evaluating neck and back fatigue profiles in male pilots. This capability allows for the biomechanical and computer modeling of in-flight responses of the head and neck.

Presently, there are no reports of neck and back fatigue profiles of female helicopter pilots wearing various helmet configurations. In addition, the effects of exercise to strengthen neck and back muscles and reduce soft-tissue injury in female helicopter pilots have not been evaluated. The current study was designed to collect simultaneous in-flight EMGs and video recordings of head movements, and to evaluate neck and back fatigue in both female and male pilots using this technology.

BODY

The objectives of this work were fourfold: (1) to conduct a survey of helicopter flight personnel to determine the prevalence of musculoskeletal pain associated with helicopter operations; (2) to determine whether female aviators showed musculoskeletal fatigue during flight; (3) to determine whether a physical training program, designed to strengthen the neck and back muscles, could decrease the incidence and delay the onset of fatigue in the cockpit aircrew, and (4) to model the extent that the helmet contributes to neck fatigue among female aviators.

STUDY 1: SURVEY OF NECK AND BACK SYMPTOMS AMONG HELICOPTER AVIATORS.

The purpose of this study was to document the incidence of neck and back musculoskeletal pain associated with helicopter operations and to ascertain the effectiveness of self-selected exercises to reduce neck and back pain in Navy pilots.

EXPERIMENTAL METHODS:

Responses to a questionnaire (Appendix A) dealing with aviation experience, musculoskeletal symptoms related to neck and back problems, and current exercise habits were obtained from 280 helicopter personnel. Respondents were asked to provide total military flight hours, including a breakdown across airframe types, and the number of hours logged in the past 30 flying days. They were asked if they were currently on waiver for neck and back problems, whether or not they had ever been diagnosed with a neck or back injury, and the number of times in the last 30 flying days that they had experienced neck and back symptoms (i.e., dull ache, sharp pain, radiating pain, numbness or tingling in the extremities, or loss of strength, dexterity, or range of movement in the extremities) during or immediately following a flight. In addition, respondents were asked whether they performed muscle strengthening exercises. If they did, they were asked to answer questions surveying the type of exercise and general muscle groups worked (i.e., neck, shoulder, back, upper abdominals, lower abdominals, buttocks, and legs).

RESULTS:

Respondents were 275 males and 5 females. Two hundred seventy-three of the respondents classified themselves as aviators (pilots or copilots); four classified themselves as flight officers, and three as aircrew. Respondents listed six different airframes as their primary aircraft: AH-1 (44), H-2 (9), H-3 (23), H-46 (56), H-53 (37), and H-60 (111). Males in this sample were older (mean age = 31.9 ± 5.2 vs. 26.4 ± 3.8 years; $t = 3.20$, $p < 0.05$) and had more total military flight hours (1,743 ± 1,174 vs. 758 ± 643; $t = 3.32$, $p < 0.05$) than the women.

Of the 280 respondents, only 195 reported flight hours within the last 30 flying days. Because the symptoms were gathered over the last 30 flying days, only these 195 respondents were used to evaluate relationships between various airframes and musculoskeletal symptoms.

Occurrence of Symptoms.

Of those with flight time within the last 30 flying days, 65 (33.3%) reported at least one instance of back symptoms (dull ache or sharp pain in the back, radiating pain, numbness or tingling in the extremities, or decreased muscle strength in the legs). Thirty-six (18.5%) reported neck symptoms (dull ache or sharp pain in the neck, or radiating pain, numbness or tingling in the arms).

Relationship to Airframe.

Table 1 shows the prevalence of back symptoms by airframe. None of the AH-1 aviators had flying time within the last 30 flying days and were excluded from Table 1. The distribution of symptom prevalence was found to differ significantly ($\chi^2 = 10.65, 4$ df, $p < 0.05$) from the expected value. H-2 aviators reported no back problems, while approximately 40% of H-53 and H-60 aviators reported problems. Table 2 shows the prevalence of neck symptoms by airframe. Prevalence of neck symptoms was found not to differ significantly across airframes ($\chi^2 =$ 4.96, 4 df, NS).

Table 1. Occurrence of Back Symptoms by Airframe

Airframe:	H-2	H-3	H-46	H-53	H-60	Total
No Symptoms (column %)	9 (100%)	19 (82.6%)	12 (80.0%)	22 (59.5%)	68 (61.3%)	130 (66.7%)
Symptoms Reported (column %)	0 (0%)	4 (17.4%)	3 (20.0%)	15 (40.5%)	43 (38.7%)	65 (33.3%)
Total (percent of sample)	9 (4.6%)	23 (11.8%)	15 (7.7%)	37 (19.0%)	111 (56.9%)	195 (100%)

Table 2. Occurrence of Neck Symptoms by Airframe

Airframe:	H-2	H-3	H-46	H-53	H-60	Total
No Symptoms (column %)	7 (77.8%)	22 (95.7%)	11 (73.3%)	30 (81.1%)	89 (80.2%)	159 (81.5%)
Symptoms Reported (column %)	2 (22.2%)	1 (4.3%)	4 (26.7%)	7 (18.9%)	22 (19.8%)	36 (18.5%)
Total (percent of sample)	9 (4.6%)	23 (11.8%)	15 (7.7%)	37 (19.0%)	111 (56.9%)	195 (100%)

Relationship to Age and Total Flight Time.

The presence of back and neck symptoms was found to vary with age and number of flight hours. Figure 1 presents the percentage of respondents reporting back symptoms as a function of age. Included in the figure are the number of respondents reporting back symptoms and the total number of respondents in each age category. The percentage of respondents reporting symptoms is substantially lower for the two oldest age groups compared with the two youngest. This pattern differs significantly from the expected values based on the distribution of respondents across age groups and average number reporting symptoms ($\chi^2 = 10.59$, 4 df, $p < 0.05$). As expected, age correlated with the total number of flight hours (r = 0.83, $p < 0.001$). However, the pattern of back symptoms reported as a function of number of flight hours differs from that seen with age. Figure 2 shows the percentage

reporting back symptoms based on total flight hours rounded to the nearest 1000 hr. Features of the figure are identical to those seen in Figure 1. The pattern observed differs significantly from that expected (χ^2 = 18.08, 4 df, $p < 0.01$). However, the pattern is "U" shaped with increasing flight hours, falling to a minimum at the 3000-hr group, then increasing with accumulated flight time. The pattern reported for neck symptoms is similar to that for back symptoms. Figures 3 and 4 provide a representation of the relationships between neck pain and age or flight time similar to that shown in Figures 1 and 2, respectively, for back symptoms,. The deviation from expected values is significant for the relationship between neck symptoms and flight hours (χ^2 = 10.47, 4 df, $p < 0.05$), but not for symptoms and age (χ^2 = 1.66, 3 df, NS); although the pattern of neck symptoms is similar to that for back symptoms.

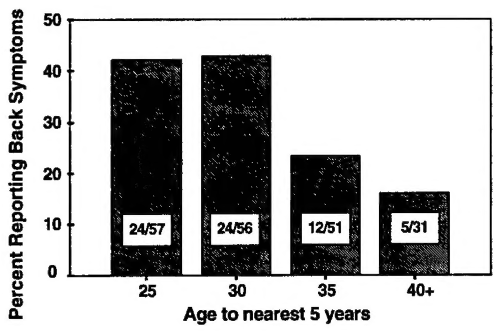


Figure 1. Relationship between back symptoms and age. Number in each group reporting symptoms is shown on the bar (numerator) with the total number in the group (denominator).

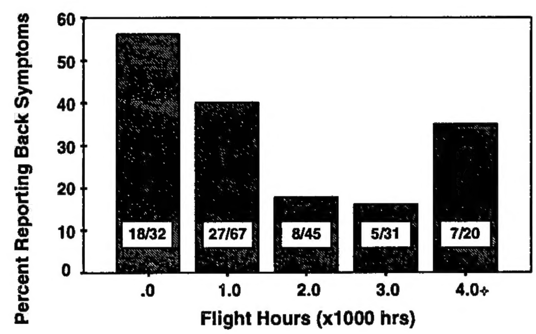


Figure 2. Relationship between back symptoms and total flight hours. Number in each group reporting symptoms is shown on the bar (numerator) with the total number in the group (denominator).

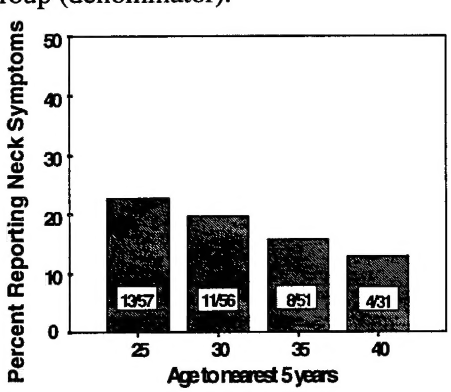


Figure 3. Relationship between neck symptoms and age. Numbers above each bar indicate the number in the group reporting neck symptoms (numerator) as well as the total number in each group (denominator).

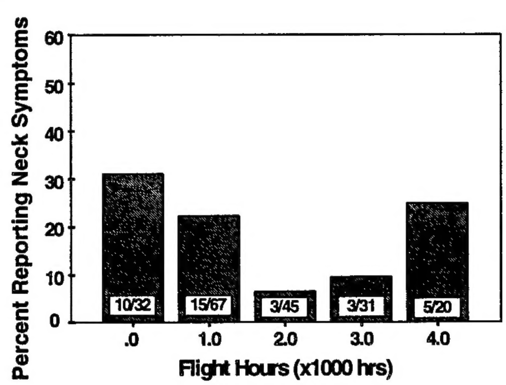


Figure 4. Relationship between neck symptoms and total number of flight hours. Numbers above each bar indicates the number in the group reporting neck symptoms (numerator) as well as the total number in the group (denominator).

Relationship to Exercise.

Relationships between the aviators self-selected exercise parameters and back and neck symptoms were investigated. Neither back nor neck symptoms were significantly associated with whether or not the aviators exercised ($r = -0.07$ for back symptoms and exercise, $r = -0.08$ for neck symptoms and exercise). Investigation of correlations between the number of exercise sessions carried out for specific muscle groups revealed only one that was significant: the incidence of back symptoms and the number of neck exercise sessions conducted over the previous 30 flying days ($r = -0.16$, $p < 0.05$).

Logistic regression was used to develop predictive models for the occurrence of back and neck symptoms. The dependent measure was the presence or absence of back or neck symptoms. Predictors were age, number of flight hours, and number of exercise sessions for each general muscle group. The model developed for the prediction of back symptoms is:

$$\mathbf{Odds_{back\ symptoms} = exp[(-0.119 \times (age\ in\ yr) - 0.268 \times (\#\ neck\ exercise\ sessions) + 3.178)]}$$

The significant predictors were those expected from the relationship between back symptoms and exercise patterns presented above: age and the number of neck exercise sessions conducted over the last 30 flying days. A model to predict the odds of neck symptoms could not be developed from these variables.

DISCUSSION AND CONCLUSIONS:

Due to the small number of female aviators in the helicopter squadrons surveyed, it was difficult to recruit female aviators for these studies. Thus, the number of females included in this survey was too small to allow meaningful comparisons of symptoms between genders.

While the number of back symptoms and number of neck symptoms are significantly correlated ($r = 0.53$, $p < 0.001$), it is noteworthy that their pattern of expression differs across airframes. The airframe associated with the highest level of back symptom reporting (H-53), is not the one associated with the highest level of neck symptom reporting (H-46). While the unequal distribution of respondents across airframes suggests a need to replicate these findings, comparison of the vibration and postural characteristics of these aircraft may offer clues to the design of more ergonomic helicopter seats.

The relationships between symptom reporting and age and symptom reporting and flight hours are not as expected. Previous work suggests that the level of chronic pain should rise with accumulated flight hours and therefore, with age (3,4). One possible interpretation of these results is that after aviators accumulate 1400 to 2400 hr of flight time, those who experience the greatest discomfort give up flying. This would account for the "dip" in the relative frequency of symptom reporting. The rise in relative symptom frequency after 2000 to 3000 accumulated flight hours may represent an increase in cumulative symptomatology associated with continued flight hours, as well as the curve for "resistant" individuals. The decrease in symptomatology among the older age groups suggests that as pilots are moved to administrative jobs as they age, the more "resistant" pilots remain on the job longer.

The relationship between exercise sessions and reporting of symptoms appears weak. Recording of exercise as number of sessions without any description of the duration, intensity, and exact nature of the exercise does not allow for an adequate definition of the volume of training. This information might allow clarification of the relationships between exercise and neck and back discomfort. Additionally, more information on any variations in

equipment worn in-flight by the aviator needs to be documented, as the equipment itself may contribute to the fatigue rate.

The logistic model to predict reports of back symptoms summarizes the major findings of this study. The older the pilot, the more likely they are to have survived the operational selection process and a "resistant" individual. Neck exercise appears to have a beneficial effect in reducing the likelihood of reporting back symptoms associated with helicopter flight.

STUDY 2: MEASUREMENT OF MUSCLE FATIGUE IN-FLIGHT.

The purpose of this study was to measure fatigue in the back and neck musculature using EMGs and to determine whether female pilots develop fatigue at a different rate than male pilots.

EXPERIMENTAL METHODS:

Four female and seven male pilots, all SH-60 aviators, were recruited for this study from the Naval Air Station (NAS) North Island, Coronado, CA. Participant characteristics are provided in Table 3. Males and females were found not to differ significantly on any characteristic (Kruskal-Wallis one-way ANOVA, $p < 0.05$ for significance). EMG signals were recorded from these pilots during training flights in the San Diego area.

Table 3. Participant Characteristics*

	Males (N = 7)	Females (N = 3)	Total Sample (N =10)
Age (yrs)	27.7 (± 2.3)	26.7 (± 0.6)	27.4 (± 2.0)
Height (cm)	178.2 (± 13.5)	176.1 (± 6.4)	177.5 (± 11.5)
Weight (kg)	73.0 (± 8.8)	68.1 (± 8.1)	71.5 (± 8.5)
Military Flight Hours	598 (± 447)	616 (± 176)	604 (± 364)

*Values shown are means (± SD)

Sets of three surface EMG electrodes (4 mm, Blue Sensor, Medicotest A/S; Olstykke, Denmark) were placed on the middle of the belly of the right sternocleidomastoid muscle (neck), and on the right side of the back in the region of the third intervertebral lumbar space, 3 cm from the midline over the belly of the supraspinalis muscle (back).

Signals were acquired using small (200 g) amplifiers attached to the surface electrodes. The amplifiers had 120dB common mode rejection and an automatic DC offset negation. The signal was filtered at the amplifier with the built-in Butterworth filter (bandpass = 20 to 480 Hz). Input impedance was 10 Gohm. Two channels of EMG signals were digitized (12-bit A/D converter) and recorded using the Mega Electronics ME3000P Muscle Tester sampling at 1,000 Hz.

Three small, lightweight (85 g) video cameras were placed in the cockpit and used to film the pilot's head movements. Two of the cameras filmed the pilot's face, with one of the cameras placed at the lower edge of the control panel and the other on the upper edge on the opposite side of the cockpit. The third camera was placed high in the cockpit behind the pilot, viewing the helmet from above and behind. The video signal and EMG recordings were synchronized by a pulse placed on the EMG event channel and the video signal. The video images were used to determine the timing of the head movements and synchronized with the EMG signals.

Data were collected during a set of planned head movements carried out at different times during flight operations. The head movements consisted of: (1) full rotation to the right, (2) full rotation to the left, (3) return to the neutral position, (4) full extension, (5) full flexion, and (6) return to neutral position. This set of movements were repeated three times on each of seven occasions during the flight. The maneuvers were performed: (1) on the ground during preflight with the engine off and rotor not turning; (2) on the ground during preflight with the engine running and the rotor turning; (3) during the flight, at the completion of one third of the flight; (4) at the halfway point of the flight; (5) during the flight with two thirds of the flight completed; (6) on the ground during postflight with engine running and rotor turning; and (7) on the ground during postflight with the engine off and the rotor stopped. A photographic representation of the movement and associated graphic EMG data are contained in Appendix B. None of the flights were of equal duration, resulting in a great variability in the period between phases 3, 4, and 5.

For this report, only EMG signals from the neck associated with movement of the head from the right to the left during the first movement were analyzed. Because past work suggested that neck movements were associated with simultaneous firing in the lumbar paraspinal muscles (Pozos, R.S. unpublished data), back EMG recordings were analyzed for time periods based on the "bursts" of activity in the neck seen accompanying the first head movement (Appendix C).

EMG signals were rectified and smoothed with a 9-point moving average. A 500-ms window was lagged in 250-ms increments through the period described by the first neck burst. The time of initiation and completion of analysis was determined from visual inspection of the EMG record. EMG magnitude was calculated for each 500-ms period as the RMS average of the smoothed signal. Median power frequency (MdPF) was determined for each 500-ms period from the fast fourier transform of the data. MdPF was calculated as the median value of the cross-products of the amplitude and the frequency associated with that amplitude (23). The reported RMS and MdPF averages represent the mean of the values calculated for each 500-ms window included in the initial burst. Fatigue was considered present if there was an increase in RMS amplitude or a decrease in MdPF.

Due to the fact that the helicopter flight, and maneuvers were of varying durations, and had varying degrees of complexity, only the data for Times 1 and 2 (preflight) and 6 and 7 (postflight) were analyzed. Separately the sample sizes for males and females were insufficient to determine gender effects and/or time by gender interactions; therefore, the data were pooled across genders for analysis. Changes in RMS or MdPF values associated with the flight were determined using the Friedman two-way analysis of variance (24). *Post-hoc* analyses were carried out using the Wilcoxon match-pairs signed-ranks test (24). Significance was accepted for $p \leq 0.05$.

RESULTS:

Mean EMG RMS amplitude and MdPF for the two preflight stages and two postflight stages for both the neck and back are provided in Table 4. The raw data are provided in Appendix D. The RMS amplitudes recorded for the neck were approximately sevenfold those recorded for the back and differed significantly at each time period. MdPF values for the neck were significantly lower than those for the back at Time 6 ($Z = -2.6$, $p < 0.05$)

and at Time 7 ($Z = -1.7$, $p < 0.05$) Analysis of variance revealed significant variation with time for both the neck ($\chi^2 = 7.6$, 3 df, $p = 0.05$) and the back MdPF ($\chi^2 = 8.3$, 3 df, $p < 0.05$). The postflight neck MdPF values were less than the preflight values, although only the difference between Time 1 and Time 7 values was significant. The mean back MdPF values recorded at Time 6 was significantly greater than those recorded at all other times.

Table 4. Mean (± SD) EMG Responses to Helicopter Flights

	RMS Amplitude, Neck (N = 6)	Median Power Frequency, Neck (N = 7)	RMS Amplitude, Back (N = 7)	Median Power Frequency, Back (N = 7)
Time 1: Preflight, rotors off	24.6 (± 13.2)	17.5 (± 2.8)	4.8 (± 7.0)	19.8 (± 5.8)
Time 2: Preflight, rotors on	23.9 (± 16.6)	17.7 (± 6.2)	2.4 (± 2.1)	19.1 (± 5.2)
Time 6: Postflight, rotors on	24.0 (± 9.0)	15.1 (± 3.1)	3.3 (± 1.5)	24.4 (± 5.4)**
Time 7: Postflight rotors off	20.2 (± 10.1)	14.2 (± 3.3)*	2.8 (± 1.5)	19.2 (±5.1)

* differs significantly from values at Time 1 ($p < 0.05$).
**differs significantly from values at all other times ($p < 0.05$).

DISCUSSION AND CONCLUSIONS:

The small sample size in this study militates against drawing meaningful conclusions regarding fatigue in the neck and back muscles associated with these helicopter operations. The sample size was not adequate to allow investigation of potential gender differences in response.

The decrease in MdPF seen in the sternocleidomastiod muscle is consistent with the development of fatigue in this muscle, whereas no decrease was seen in the back muscles measured. The finding of neck, but not back, fatigue is surprising since the majority of the data available suggest more frequent development of back pain, compared to neck pain, in helicopter pilots (25 [Table B-9, Appendix B]).

The authors found no previous reports of fatigue in the sternocleidomastoid muscle. The action of this muscle is to rotate and tilt the head, and would not necessarily be expected to have substantial involvement in stabilizing the head and helmet. It is, however, involved in rotation of the head. Further examination of the video images recorded during flight may suggest head motions in which sternocleidomastoid plays a stabilizing role. However, the fatigue seen in these muscles may be a result of vibration, rather than direct muscular activity. It would be important to replicate this finding in future studies.

Very little activity was seen in the back muscles, as evidenced by the rather low RMS amplitudes. This finding may be a result of the measurement paradigm. Back muscle activity was measured only during deliberate head and neck movements. Activity in the back muscles may have been greater during other times in the flight,

such as during turning and banking the aircraft. The present study design may not have been optimal for characterizing function and fatigue in the back muscles.

STUDY 3: EFFECTS OF NECK AND BACK PHYSICAL CONDITIONING.

EXPERIMENTAL METHODS:

The third study evaluated physical training as an intervention to decrease the development of fatigue during helicopter flight. Participants in this study were the female and male pilots who took part in Study 2. Participants undertook an 8-week neck and back strength training program, consisting of two sessions each week. Participants performed neck extension and neck rotation exercises using MedX exercise machines designed specifically for those exercises, and a back extension exercise using a "roman chair." Neck extension, neck rotation, and back extension strength and endurance were measured during the first session, the 8th session (midway through the training), and the 16th session (end of training).

Strength and Endurance Testing: Neck extension was tested in the following way: (1) The participant was seated in a MedX cervical extension machine with pads compressing the thorax and a belt placed around the waist. A pad was positioned behind the participant's head. The participant extended his/her neck, pushing the head back against the head pad. Torque and angle were transduced through a strain gauge sensor attached by a lever to the back of the pad. For isometric tests, the angle of the neck was adjusted by moving the extension pad forward and backward. Participants warmed up with six repetitions of isoinertial neck extension. Torque resistance was set to 0.69 kg-m for females and 1.04 kg-m for males. (2) Participants then practiced three isometric extensions at 50% effort with the neck flexed, in the middle of the extension range, and fully extended. (3) Participants were then tested for maximal isometric strength at 126°, 108°, 90°, 72°, 54°, 36°, 18°, and 0° extension. Neck extension strength was expressed as the sum of the isometric torque, in kg-m, exerted at each angle. (4) Following the isometric testing, the participants exercised dynamically at 80% of peak torque, derived from the isometric test, until volitional fatigue.

Neck rotation was tested in the following way: (1) The participant was seated in a MedX cervical rotation machine, with pads compressing the thorax and a belt around the waist. The head was fixed in a device attached to a shaft descending from the top of the machine and encompassing the skull bitemporally. As the head rotated, torque and angle were measured by sensors at the end of the shaft. Participants warmed up with six repetitions of neck rotation from -72° to +72° with the torque resistance fixed at 0.23 kg-m for female and 0.345 kg-m for male. (2) A three-angle practice for the isometric test was then carried out at full left rotation, neutral position, and full right rotation at approximately one half maximal effort. (3) Participants were then tested for maximal isometric strength at 72°, 48°, 24°, 0°, -24°, -48°, and -72° of rotation, testing first left rotation, then rotation at each angle. Strength was expressed for both left and right rotation of the head as the sum of the isometric torque generated at each angle. (4) Participants then exercised dynamically until volitional fatigue, alternating left and right rotations, with work set to 80% of the maximal torque achieved during the isometric testing.

For back extension testing, the roman chair consisted of a frame on which rested a pad to support the pelvis and a bar under which to hook the feet. The participant lay on the pad in a prone position with the feet hooked under the bar. This allowed the body to flex at the waist until the head was pointed toward the ground. The participant then extended the back to raise the torso to a horizontal position. Back extension endurance was tested by having the subject complete 24 extensions consisting of 3 s to lower, 3 s to raise, and 1 s to hold the torso in a horizontal position. The participant then maintained the 25th extension in the horizontal position for as long as possible, with hold time measured to the nearest second. Several individuals could not perform the required 25

extensions. In these cases, the number of repetitions for the initial test was noted and a zero time was assigned. That number of repetitions was used in subsequent tests as the basis for measuring hold time.

Training Program: The training program consisted of neck extension, neck rotation, and back extension training twice a week. Neck extension training consisted of dynamic isoinertial exercise on the MedX machine. The participant completed sequential neck extensions, with a starting resistance of 80% of the peak torque recorded during the initial isometric test. Each time the participant could complete 20 repetitions, the torque resistance was increased by 5%.

Neck rotation training consisted of dynamic/isometric exercise on the MedX machine. The participant completed alternating left and right neck rotations, with a starting resistance of 80% of the peak torque recorded during the isometric test. Each time the participant could complete 20 repetitions, the resistance torque was increased by 5%. The order of neck extension and neck rotation training was reversed on alternate training days.

Back extension training consisted of 25 extensions on the roman chair. When the participant could complete 25 repetitions, weight on the upper torso was incremented by 5 lb. The effects of the training program were evaluated using a Wilcoxon Matched-Pairs Signed-Ranks Test. Gender comparisons were made using the Kruskal-Wallis 1-Way Analysis of Variance. In all cases, the probability for significance set at $p \leq 0.05$

In-flight EMG: After the 8-week strengthening program, a second in-flight helicopter EMG recording was conducted on the pilots. The experimental methods used were the same as those described in Study 2.

RESULTS

The training program resulted in increases in neck strength and back endurance. Table 5 shows the individual results for neck extension testing prior to and following the training program. Not all participants completed the full 8 weeks of training. Table 6 provides the mean values for neck extension, by gender. For the sample, there was a significant increase in neck extension strength ($Z = 2.19$, $p < 0.03$). Males and females differed significantly on initial and final values for neck extension strength with the females having lower values. On average, females showed a smaller increase in neck extension strength than did males. This difference approached, but did not reach significance ($p = 0.08$).

Table 5. Effect of 8-Week Strengthening Program on Cervical Extension*

SUBJ	Weeks of Training	Cervical Extension Initial (MVC)	Cervical Extension Final (MVC)	Cervical Extension % Change
1 (m)	8.0	43.73	51.29	+17.27
2 (m)	8.0	36.56	42.57	+16.43
3 (m)	8.0	35.05	39.72	+13.32
4 (f)	8.0	21.84	23.56	+7.87
5 (f)	8.0	26.54	24.81	-6.52
6 (m)	7.5	22.80	27.27	+19.63
**7 (m)	5.5	33.13	34.65	+4.59
8 (m)	5.0	35.65	35.24	-1.13
9 (m)	4.0	27.22	30.66	+12.62
10 (f)	4.5	26.20	27.56	+5.19

* Values shown are the sum of the force generated, in kg-m, at each angle during the isometric test

** performed 11 exercise sessions over the 8 weeks

MVC (Maximal Voluntary Contraction)

Table 6. Neck Extension Response to 8 Weeks of Training*

	Men (N = 7)	Women (N = 3)	Total Sample (N = 10)
Initial Test Summed Torque (kg-m)	33.4 ± 6.8	24.9 ± 2.6	30.9 ± 7.0
Final Test Summed Torque (kg-m)	37.3 ± 8.0	25.3 ± 2.0	33.7 ± 8.8
Change (kg-m)	3.9 ± 2.7	0.4 ± 1.9	2.9 ± 2.9

* Values shown are means (± SD)

Table 7 shows the individual values for left and right neck rotation strength for the initial and final tests. Means for these values, by gender, are provided in Table 8. Again, for this sample, there were significant increases in left ($Z = 2.60$, $p < 0.01$) and right ($Z = 2.70$, $p < 0.01$) rotational strength. Females had significantly lower rotational strength than males for both left and right rotations, and on both the initial and final tests (in each case,

$\chi^2 = 5.73$, $p < 0.02$ for the gender comparison). The females improved less than the males in rotational strength. This difference was significant for rotation to the left ($\chi^2 = 4.69$, $p < 0.04$) but not for rotation to the right.

Table 7. Individual Results of 8-Weeks Training on Cervical Rotation Maximal Voluntary Contraction

Subject	Weeks of Training	Initial Right Rotation MVC (kg-m)	Final Right Rotation MVC (kg-m)	Initial Left Rotation MVC (kg-m)	Final Left Rotation MVC (kg-m)
1 (m)	8.0	11.95	16.49	7.25	12.54
2 (m)	8.0	8.64	12.86	6.19	8.68
3 (m)	8.0	35.05	39.73	7.98	13.34
4 (f)	8.0	4.05	6.65	2.94	3.52
5 (f)	8.0	3.62	5.83	3.15	2.77
6 (m)	7.5	6.31	9.52	4.84	5.80
*7 (m)	5.5	10.38	10.84	5.02	5.81

*performed 11 exercises sessions over the 8 weeks.
MVC (Maximal Voluntary Contraction)

Table 8. Neck Rotation Strength Response to 8 Weeks of Training*

	Men (N = 7)	Women (N = 3)	Total Sample (N = 10)
Left Rotation:			
Initial Test Summed Torque (kg-m)	5.6 ± 1.5	2.9 ± 0.3	4.8 ± 1.8
Final Test Summed Torque (kg-m)	8.0 ± 3.6	3.0 ± 0.4	6.5 ± 3.8
Change (kg-m)	2.4 ± 2.1	0.1 ± 0.4	1.7 ± 2.1
Right Rotation:			
Initial Test Summed Torque (kg-m)	12.2 ± 10.3	4.2 ± 0.8	9.8 ± 9.2
Final Test Summed Torque (kg-m)	15.0 ± 11.3	5.8 ± 0.9	12.2 ± 10.3
Change (kg-m)	2.8 ± 1.8	1.5 ± 1.5	2.4 ± 1.8

* Values shown are means (±SD)

Table 9 provides the individual values for back extension (roman chair) hold times and Table 10 shows the mean values. Back extension endurance increased significantly (Z = 2.20, $p < 0.03$) for the sample as a whole. On average, the females in this sample had a greater endurance time than the males. The gender comparison approaches, but did not achieve significance for the final test ($\chi^2 = 3.75$, $p = 0.052$). No significant difference between genders was found for the magnitude of change in endurance time.

Table 9. Results of Training on Back Extension Hold Time

SUBJECT (Male/Female)	Initial Hold Time (s)	Final Hold Time (s)	Change (s)
Subject 1 (m)	24	45	+21
Subject 2 (m)	14	45	+31
Subject 3 (m)	61	190	+129
Subject 4 (f)	21.5	225	+203.5
Subject 5 (m)*	0	117	+117
Subject 6 (m)*	0	79	+79
Subject 7 (m)*	0	41	+41
Subject 8 (m)	8	18	+10
Subject 9 (m)*	0	53	+53
Subject 10 (f)	70	85	+15

*Subject did not complete 25 repetitions on initial test. Final measurement based on number of repetitions completed in initial test.

Table 10. Back Extension Endurance Response to 8 Weeks of Training*

	Men (N = 7)	Women (N = 3)	Total Sample
Initial Extension Hold Time (s)	15.3 ± 22.1	30.5 ± 35.9	19.8 ± 25.8
Final Extension Hold Time (s)	67.3 ± 57.0	142.3 ± 73.4	89.8 ± 68.4
Change (s)	52.0 ± 40.7	111.8 ± 94.4	70.0 ± 62.6

* Values shown are means ± (SD)

Shortly after completion of the 8-week strengthening phase of the study, the pilots performed a second in-flight procedure. However, due to scheduling conflicts and unexpected squadron training requirements, there was an average of a 2 to 3 week delay between the pilot's completion of the 8-week program and the postexercise flight. As a result, the postexercise in-flight data are incomplete and did not allow statistical analyses.

DISCUSSION AND CONCLUSIONS:

The training program increased neck strength and back endurance. The females in this sample had less neck strength than the males, despite being well-matched on physical characteristics and flight experience (Table 3). The strength difference is in keeping with past literature suggesting that even when matched on size, females have less upper body strength than males. For the same level of activity, females commonly have a greater body fat content by about 10% of body weight. It would be expected that these females have less lean mass than their male counterparts, which could account for the lower strength levels.

The females had greater back endurance, on average, than the males. If this finding can be generalized to the helicopter community at large, it would be important to carry out surveys of neck and back symptoms to include more females. It also would be important to determine whether this greater back endurance was associated with a lower number of back symptoms for comparable flight time.

The strength data demonstrate that female pilots had less strength than males for all the neck exercises, particularly for rotation. Female pilots, therefore, may be more susceptible to muscle pain and injury in the neck and back than males. These data corroborate other data collected by NAVHLTHRSCHCEN indicating that neck strength is greatest in the anterior/posterior plane, and that the greatest improvement in neck strength occurs during right and left rotation. Neck and back strengthening exercises should be emphasized to decrease muscle fatigue, delay fatigue onset, and reduce chronic soft-tissue injury in this population. The specific exercises that should be used for optimal effect are yet to be determined.

STUDY 4: MODELING OF HELMET EFFECTS ON NECK AND BACK FATIGUE.

The purpose of this study was to validate a mathematical model of head loading designed to evaluate the fatigue-inducing properties of various helmet configurations and to assist in the design of new helmets.

EXPERIMENTAL METHODS:

To evaluate the fatigue-inducing characteristics of the standard Navy helmet, Army pilots were tested on the Multiple Axis Ride Simulator (MARS) at the U.S. Army Aeromedical Research Laboratory (USAAMRL) at Ft. Rucker, Alabama. A computer flight profile was developed to mimic the jolt impact of a UH-60 helicopter, the Army version of the Navy's SH-60. The flight profile used on the MARS was recorded from a UH-60 during a straight-and-level flight at 120 knots indicated airspeed. Two subjects donned the Army helmet and "rode" on the MARS for 2 hr, simulating the duration of a short helicopter mission.

The pilots were prepared for surface EMGs and video recordings. Surface electrodes were placed on the cervical muscle (Level C4-5), sternocleidomastoids, and back extensor (lumbar 3-4) muscles. The test profile was programmed to mimic the in-flight profiles performed in Study 1. Surface EMGs and videos were recorded simultaneously during the flight simulation as in Study 1. Originally, the data from these simulated flights were to be used to: (1) document the similarity in helicopter vibration profile, (2) demonstrate the same in-flight EMG profile seen in Navy pilots (Study 2), and (3) validate a computer-based head and neck model. Due to problems with the vibration profile (see Results), data collection on the MARS was abbreviated.

RESULTS:

Comparing spectral analyses of the vibration profiles of pilots at Ft. Rucker with those of the in-flight recordings of Navy pilots in the SH-60 indicated that the profiles were distinctly different. Horizontal displacement, velocity, and acceleration on the MARS were greatly attenuated, compared to the in-flight scenario (Appendix E).

Table 11 presents the raw data from one female pilot tested on the MARS. The back EMG amplitudes increases overtime, while the neck EMG amplitudes decrease.

Table 11. MARS EMG Recordings on One Female Pilot Bursts 1 and 3

TIME (min)	Back EMG (μV) Burst 1	Back EMG (μV) Burst 2	Neck EMG (μV) Burst 1	Neck EMG(μV) Burst 2
0	24	24	330	322
15	27	24	342	336
30	24	24	381	404
45	27	30	336	345
60	41	41	330	333
75	50	80	363	136
90	62	62	109	145
105	71	50	292	307

Visual examination of these in-flight data indicate that there were four EMG patterns of activation: (1) tonic back muscle firing independent of head movement, (2) phasic firing of the back muscles during neck extension, (3) tonic firing of back muscles during neck extension and rotation, and (4) phasic firing of back muscles during neck extension and rotation.

DISCUSSION AND CONCLUSIONS:

The EMG and video data collected on the MARS indicate that 2 hr on the vibration platform was not adequate to produce neck and/or back fatigue. Analysis of lumbar EMG activity indicated that the flight induced a prolonged increase in the amplitude of the signal.

BIOMECHANICAL MODEL OF HEAD LOADING ON CERVICAL MUSCULATURE

A biomechanical computer model that computes and displays forces acting on the cervical spine was developed. As the helmet causes the neck muscles to fatigue, the need for head stabilization may lead to subsequent firing of the lumbar musculature. The long-term goal of this research was to develop a kinematic model to predict the net forces on the cervical vertebrae based on the forces generated by a helmet. Once the model is validated, it will be possible to reduce the potential for neck fatigue by individually altering a pilot's

helmet through strategic placement of small counterweights to minimize cervical torques and consequently, fatigue and pain.

The biomechanical model was a modified form of work by Snijders (26). The model is currently 75% complete and will be completed when additional information on helmet specification's is available. Additional data from the Navy are being incorporated into the second generation model. Various helmets will be modeled, incorporating the center of mass of the pilot's head. The model then can be used to decrease neck and back fatigue.

Pages 1 and 2 of Appendix F show the introduction to the computer program and demonstrate the forces that can be modeled, using specific boney landmarks. Pages 3 to 5 demonstrate examples of the top, side, and front view of the neck with flexion, lateral excursions, bending and axial rotation in various positions. Pages 6 to 8 show the output of the model detailing the forces produced at select vectors. The program provides the user the ability to change head angle and linear acceleration. Pages 7 and 8 show the resultant forces on the cervical musculature, with the darkest line representing the overall resultant force. Pages 9 and 10 indicate how various helmet configurations can be programmed into the model to predict the resultant center of gravity. As the center of gravity of the helmets and head change, there is a resultant change in the forecasting of overall forces on the neck musculature. These forces either may increase or decrease neck muscle fatigue depending on the in-flight maneuvers being executed.

This model can calculate the forces exerted on the neck musculature of military pilots with and without helmets. Other models (26) were developed without in-flight EMG data correlated with acceleration and position. In addition, most models do not consider the role of the back in stabilizing the neck or the functional asymmetry between the paraspinals of the vertebral column (26). Helmet configuration that reduces neck fatigue should also delay the onset of back fatigue and ultimately reduce neck and back pain.

CONCLUSIONS

The attempt to reproduce on the MARS the patterns of EMG seen during actual training flights was unsuccessful. However, a useful model of the forces and moments about the head during flight was developed and is available as a helmet design and evaluation tool.

SUMMARY

This study was based on the assumption that helicopter pilots experience neck and back fatigue due to external forces and that the fatigue would lead to muscuskeletal or soft-tissue pain and/or injury.

In Study 1, 33.3% of Navy pilots reported back symptoms and 18.5% reported neck symptoms. Incidences of back symptoms were related to different airframes, whereas neck symptoms were independent of airframe. Due to the small number of female pilots in the sample, it was not possible to discriminate symptoms reports on the basis of gender. However, the point is established that a substantial proportion of Navy pilots suffer from both neck and back symptoms, with back being more common.

In Study 2, EMG and video recording of pilots flying helicopters was accomplished. EMG patterns of neck and back activation were detailed. Due to the varying length and complexity of the flights, statistical analyses were not possible. Nevertheless, there was neck and back activity during the flight when the pilots were handling the controls. The vibration profile did not appear to elicit more neck or back EMG activity.

In Study 3, it was determined that neck and back exercises were effective in strengthening cervical and lumbar musculature and that males and females differed significantly on initial and final neck extension strength. Also, females did not increase neck extension strength as much as males. Females show less rotational strength than males for both right and left rotation and improved less over the training session. In contrast, females had greater back endurance on the roman chair exercise than males. These data suggest that there may be a gender difference in terms of neck and back strength profiles. Due to unanticipated scheduling conflicts, we were able to have only one subject who completed training sessions to perform a second in-flight EMG and video analyses.

In Study 4, a model that predicts "net" force generated by helmets on the cervical musculature is nearly completed. This model was to be validated using the Ft. Rucker MARS simulator. However, due to the substantial disparencies between the in-flight vibration profiles of the Navy SH-60 and the profiles on the Ft. Rucker simulator, the study was not completed.

Overall, these data suggest that Navy pilots are susceptible to neck and back injuries. The factors that may contribute to these symptoms are cockpit ergonomics, helmet configuration, fatigue over flight duration, and airframe vibration. In-flight EMG and video recordings support the view that in-flight maneuvers influence the cervical and lumbar musculature.

Not all subjects demonstrated an in-flight relationship between neck and back activation and fatigue. However, since the flights were of varying duration and complexity, the absence of lumbar activation may be due to the brevity of the flight compared to tactical and training flight routines. Based on the exercise program data, female pilots may be more susceptible to neck and/or back injury. Additional studies should be conducted on female Navy pilots to ascertain if these initial conclusions are supported. If so, female Navy pilots should undergo a scientifically based exercise program to enhance neck and back strength.

Recording simultaneous in-flight EMG and video data proved unexpectedly difficult in this study. Future directions for this research would be to study pilots during prolonged flights and to include measurements of pre- and postflight flexibility. It is expected that longer flights (> 4 hr) will trigger increased lumbar activity and result in fatigue that may lead to injury or exacerbate underlying muscle weakness. Additionally, there are plans for evaluating an inexpensive, portable neck and back strengthening device for incorporation into a training program for pilots. The research could be expanded to other aviation communities, such as fixed-wing aircraft, where vibration is greater than in rotary-wing aircraft. These aircrew may experience more pronounced muscle fatigue and soft-tissue injury than that recorded in helicopters pilots.

REFERENCES

1. Shanahan, D.F., Mastroianni, G.R., & Reading, T.E. (1985). Back discomfort in U.S. Army helicopter aircrew members. In: Advisory Group for Aerospace Research & Development Conference Proceedings No. 378 on Backache and Back Discomfort. Pozzuoli, Italy: North Atlantic Treaty Organization.

2. Bowden, T.J. (1985). Postural fatigue and the backache of helicopter pilots. Defence and Civil Institute of Environmental Medicine. DCIEM Report No. 85-R-30: 24-1-24-10.

3. Bongers, P.M., Hulshof, C.T.J., Dukstra, L., & Boshuizen, H.C. (1990). Back pain and exposure to whole body vibration in helicopter pilots. Ergonomics, 33(8), 1007-1026.

4. Metges, P.J. Flageat, J., & Mouchon Y. (1986). Pain due to the spine in helicopter pilots in 1985. Results of a multicentre study. Medicine Aeronautique et Spatiale, Tome XXV, 100, 310-315.

5. Froom, P., Froom, J., Van Dyk, D., Caine, Y., Ribak, J., Margaliot, S., & Floman, Y. (1984). Lytic spondylolisthesis in helicopter pilots. Aviation, Space, and Environmental Medicine, 55(6), 556-557.

6. Bowden, T.J. (1986). Postural fatigue and the backache of helicopter pilots. Pp. 1-10. In: Advisory Group for Aerospace Research & Development Conference Proceedings No. 378: Backache and Back Discomfort. Pozzuoli, Italy: North Atlantic Treaty Organization..

7. Pope, M.H., Wilder, D.G., Seroussi, R.E., & Donnermeyer, D.D. (1985). The effects of helicopter vibration on the spinal system. U.S. Army Medical Research and Development Command. DAMD 17-84-C-414, 1-145.

8. Giordano, J. (1994). Aviator Back Syndrome and Putative Pathology and Etiology. Aviation, Space, and Environmental Medicine, 65(5), 453.

9. The AMELIA program. LCDR T. Pokorski. (1994). Analysis of flight gear for female pilots. Naval Aeromedical Research Laboratory.

10. McArdle, W.D., Katch, F.I., & Katch, V.L. (1991). Exercise Physiology. (ed.) Lea Febriger, Philadelphia, PA., pp 217-220, pp. 456-459.

11. Chaffin, D.B., & Anderson, G.B.J. (1991). Guidelines for whole-body and segmental vibration. In D.B. Chaffin & G.B.J. Anderson (Eds.), Occupational Biomechanics (2nd ed., pp. 431-463). New York:Wiley.

12. Hamalainen, O. (1992). Effect of Gz forces and head movements on cervical erector spinae muscle strain. Aviation, Space, and Environmental Medicine, 63, 709-716.

13. Smith, S.D. (1995) Inertial Loading Effects of Helmet/Head Mounted System. DF330170. Armstrong Laboratory, Wright-Patterson AFB, Ohio.

14. Lind, A.R., & Petrofsky, J.S. (1979). Amplitude of the surface electromyogram during fatiguing isometric contractions. Muscle Nerve, 2, 257-264.

15. Petrofsky, J.S. (1979). Frequency and amplitude analysis of the EMG during exercise on the bicycle ergometer. European Journal of Applied Physiology, 41, 1-15.

16. Lippold, O.C.J., Redfearn, J.W.T., & Vuco, J. (1960). The electromyography of fatigue. Ergonomics, 3, 121-131.

17. Haag, G.M. (1992). Interpretation of EMG spectral alterations and alteration indexes at sustained contraction. Journal of Applied Physiology, 73, 1211-1217.

18. Fuglsang-Frederecksen, A., & Ronager, J. (1988). The motor unit firing rate and the power spectrum of EMG in humans. Electroenceph and Clinical Neurophysiology, 70, 68-72.

19. Bilcheck, H.M., Maresh, C.M., & Kraemer, W.J. (1992). Muscular Fatigue: A brief overview. National Strength and Conditioning Association Journal, 14, 9-14.

20. Couris, M., Mooney, V., & Pozos, R. (1995). Evaluation of electromyographic indices of fatigue during repetitive lumbar isotonic flexion and extension. NAVHLTHRSCHCEN Technical Report (in review).

21. Pozos, R.S., Feith, S.J., Booth, R., & Moore, C.D. (1993). In-flight EMG measurements of neck and back muscles during sustained +Gz forces. Aviation, Space, and Environmental Medicine, 64, 455.

22. Hamalainen, O. (1993). Flight helmet weight, +Gz forces, and neck muscle strain. Aviation, Space, and Environmental Medicine, 64, 55-57.

23. Blackman, J.W., & Tukey, J.W. (1959). The measurement of power spectra, New York: Dover Publications.

24. Segel, S. (1956). Non-parametric Statistics for the Behavioral Sciences. New York: McGraw-Hill Book Company. (pp.166-172) and (pp. 75-83).

25. Village, J., Roddan, G., Brammer, T., Morrison, J., Rylands, J., Cameron, B., Smith, M., and Robinson, D. (1995). Development of a standard for the health hazard assessment of mechanical shock and repeated impact in Army vehicles, phase 1. USAARL Contract Report No. CR 95-1. Ft Rucker, AL: United States Army Aeromedical Research Laboratory.

26. Snijders, C.J., Hoek Van Dijke, G.A., & Roosch, E.R. (1991). A biomechanical model for the analysis of the cervical spine in static postures. Journal of Biomechanics, 24, 783-792.

APPENDIX A

AIRCREW NECK AND BACK SURVEY

AIRCREW NECK AND BACK SURVEY

Participant Information and Privacy Act Statement
OPNAV Survey Control No. 6260-3 (Expiring 30 SEP 94)

This questionnaire will be used to evaluate possible neck and back problems that occur while flying DoN aircraft. Additionally, it will be used to evaluate different muscle strengthening exercises utilized by naval aircrew. All the data gathered will be stored at the Naval Health Research Center and will be used for research purposes only. The data will not become a part of anyone's official records and will be reported in such a way that no individual can be identified.

You are asked to voluntarily complete this questionnaire. Although there will be no direct benefits to you, your input will contribute to the possibility of improving exercise interventions and flight equipment modifications to minimize neck and back problems of military aircrew. Refusing to participate shall not in any way be prejudicial to you or your naval career. Questions are to be directed to CDR Steven J. Feith, MSC, USN, Naval Health Research Center, P.O. Box 85122, San Diego, CA 92186-5122. COMM/DSN (619) 524-4519.

1. Authority: 5 USC 301, 10 USC 1071. 2. Purpose: Medical research information will be collected to enhance basic medical knowledge and/or to develop tests, procedures, and equipment to improve the diagnosis, treatment or prevention of illness, injury, or performance impairment. 3. Use: Medical research information will be used for statistical analyses and reports by the Departments of the Navy, Defense, and other U.S. Government agencies, provided this is compatible with the purpose for which the information was collected. Use of the information may be granted to non-Government agencies or individuals by the Chief, Bureau of Medicine and Surgery, in accordance with the provisions of the Freedom of Information Act. 4. Disclosure: I understand that all of the information derived from this study will be retained at the Naval Health Research Center, San Diego, and that my anonymity will be maintained. I voluntarily agree to its disclosure to agencies or individuals identified in the preceding paragraph, and I have been informed that failure to agree to such disclosure may negate the purposes for which the study is being conducted.

For each of the following items, please enter the **MOST APPROPRIATE** response.

1) Enter your age_______

2) Enter your gender (M or F)_______

3) Enter your rank (E-6, O-3 etc.)_______

4) Are you a Naval Aviator? (Y or N)_______

5) Are you a Naval Flight Officer? (Y or N)_______

6) Are you a Naval Aircrew? (Y or N)_______

7) Are you now or have you been an instructor pilot? (Y or N)_______

8) Are you a test pilot? (Y or N)_______

9) Are you a Top Gun graduate? (Y or N)_______

10) Enter your total military flight hours_______

11) Enter the number of flight hours logged
DURING THE PAST 30 FLYING DAYS_______

12) Enter the number of ACM flights flown
DURING THE PAST 30 FLYING DAYS_______

For questions 13-15, please enter the letter corresponding to the type(s) of aircraft that you are flying. If you have flown more than one aircraft, enter the one in which you have the most flight hours first.
PLEASE USE THE FOLLOWING KEY WHEN INDICATING AIRCRAFT TYPE:
(**Example**: For A-4M or TA-4F, enter "E"; for H-1N or AH-1W, enter "J")

A) F-4	E) A-4	I) A-10	L) H-3	O) H-60
B) F-14	F) A-6	J) AH-1	M) H-46	P) Other
C) F-16	G) A-7	K) H-2	N) H-53	Q) No Additional Aircraft
D) F/A-18	H) AV-8			

13) Aircraft flying now:_______

Total number of years_______

Total number of hours_______

14) Next most recent aircraft flown:_______

Total number of years_______

Total number of hours_______

15) Next most recent aircraft flown:_______

Total number of years_______

Total number of hours_______

16) Are you on any medical waiver for neck or back problems associated with your military flying? (Y or N)_______

17) Have you **EVER** been diagnosed with a neck injury as a result of flight in military aircraft? (Y or N)_______

18) Have you **EVER** been diagnosed with a back injury as a result of flight in military aircraft? (Y or N)_______

19) Do you perform specific muscle strengthening exercises? (Y or N)_______
IF NO, PLEASE GO TO QUESTION 46.

The following questions ask you to quantify the type of strengthening exercises that you perform on a regular basis. Please enter the number of **SESSIONS PER WEEK** that you perform the indicated exercise:

20) Isometric neck exercises:_______

21) Neck exercise with free weights:_______

22) Neck exercise with machines:_______

23) Neck exerting calisthenics:_______

24) Isometric shoulder exercises:_______

25) Shoulder exercise with free weights:_______

26) Shoulder exercise with machines:_______

27) Shoulder exerting calisthenics:_______

28) Isometric back exercises:_______

29) Back exercise with free weights:_______

Continue to enter the number of **SESSIONS PER WEEK** that you perform the exercise

30) Back exercise with machines:_______

31) Back exerting calisthenics:_______

32) Isometric buttocks exercises:_______

33) Buttocks exercise with free weights:_______

34) Buttocks exercise with machines:_______

35) Buttocks exerting calisthenics:_______

36) Isometric upper abdominal exercises:_______

37) Upper abdominal exercise with free weights:_______

38) Upper abdominal exercise with machines:_______

39) Upper abdominal exerting calisthenics:_______

40) Isometric lower abdominal exercises:_______

41) Lower abdominal exercise with free weights:_______

42) Lower abdominal exercise with machines:_______

43) Lower abdominal exerting calisthenics:_______

44) Isometric leg exercises:_______

45) Leg exercise with free weights:_______

46) Leg exercise with machines:_______

47) Leg calisthenics:_______

Please indicate the number of times WITHIN THE LAST 30 FLYING DAYS that you have experienced the following DURING OR IMMEDIATELY AFTER A FLIGHT:

48) Dull ache in neck or shoulders:_______

49) Dull ache in back:_______

50) Sharp pain in neck or shoulders:_______

51) Sharp pain in back:_______

52) Pain radiating into one or both arms:_______

53) Pain radiating into one or both legs:_______

54) Numbness, tingling, and/or prickling in hands or fingers:_______

55) Numbness, tingling, and/or prickling in legs or feet:_______

56) Decreased dexterity or movement with arms, hands, or fingers:_______

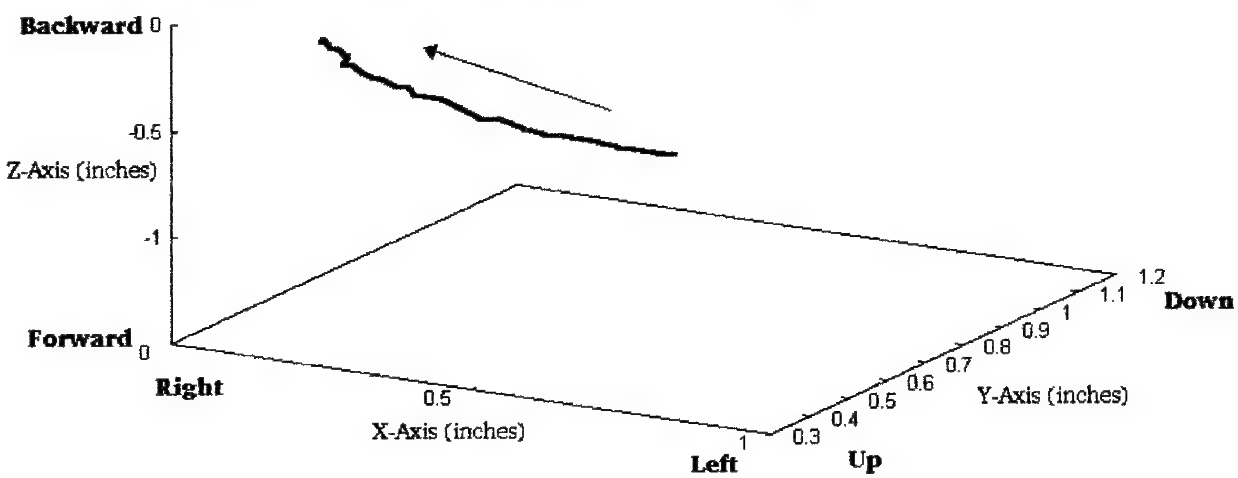
57) Decreased strength or range of motion in legs:_______

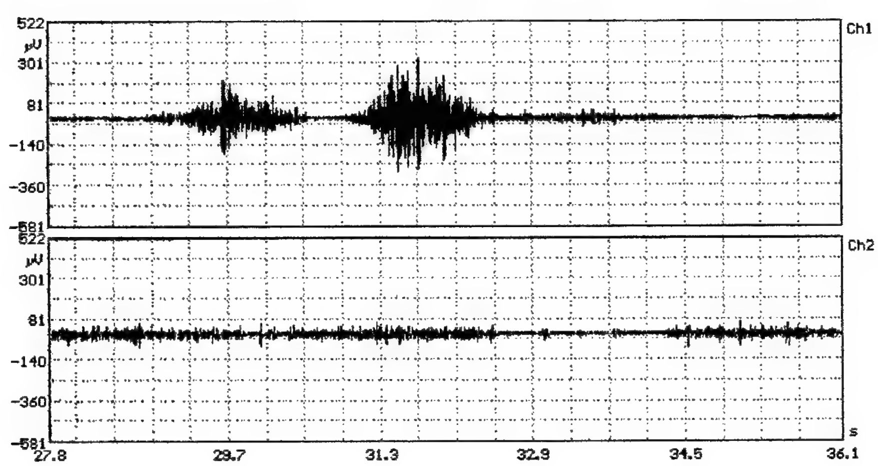
THANK YOU FOR YOUR PARTICIPATION!

APPENDIX B

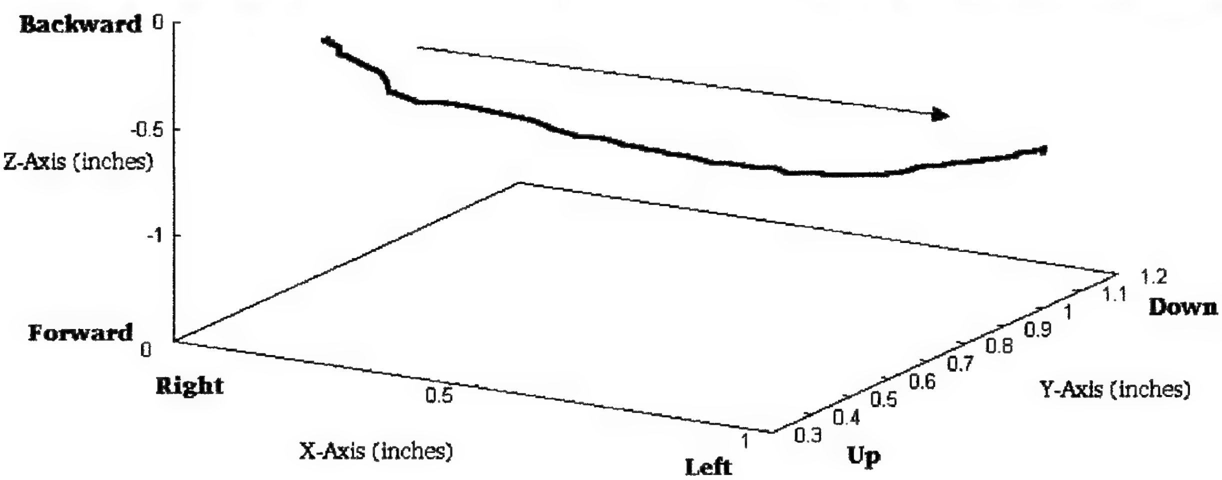
PHOTOGRAPHIC REPRESENTATION OF THE MOVEMENT AND GRAPHIC EMG DATA

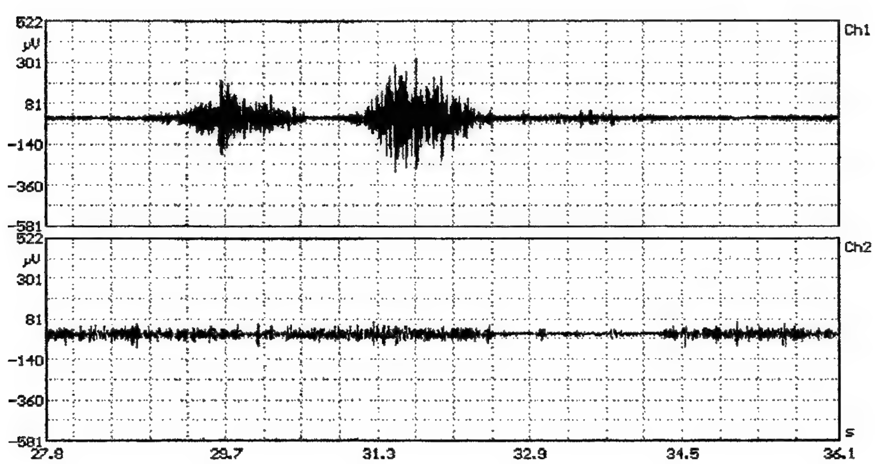
Movement of the pilot from neutral to right position.
The graph represents the trajectory of the nose.
The EMG of this movement is highlighted in yellow.



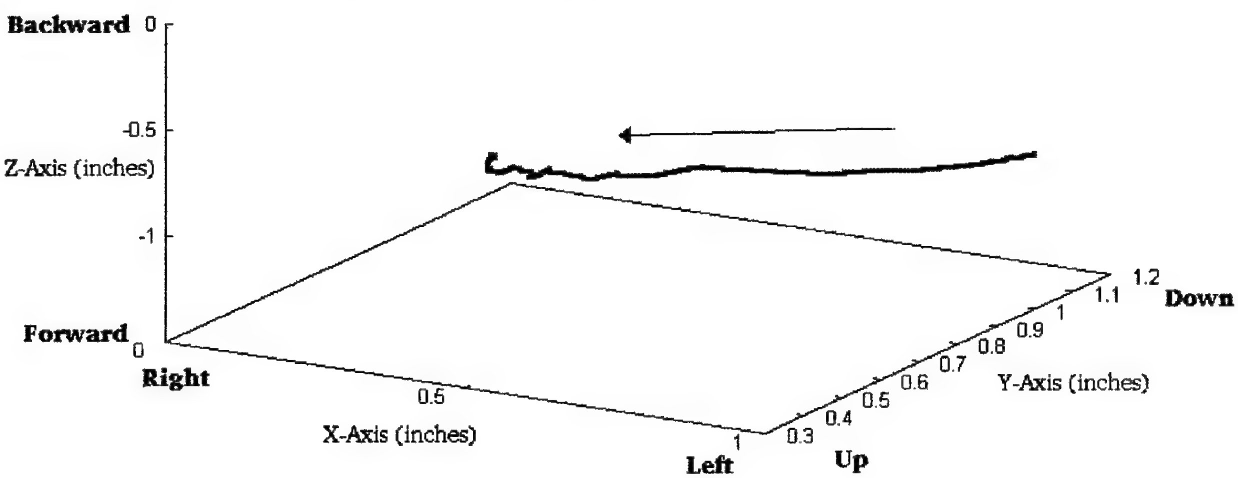


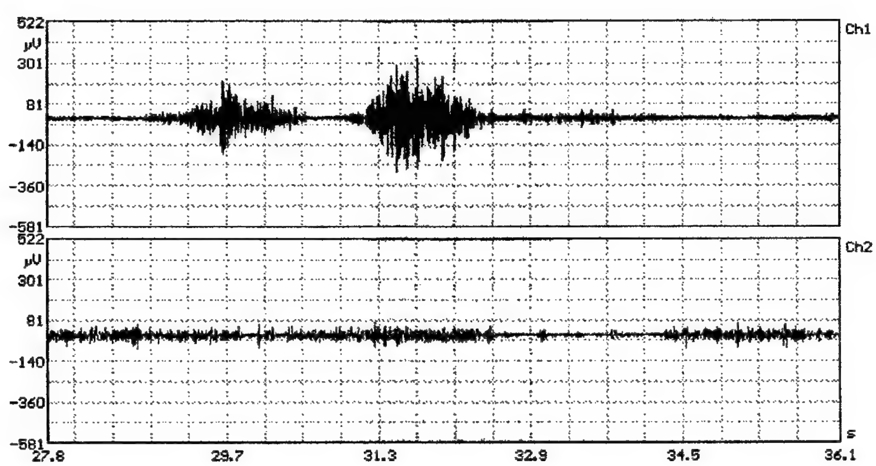
Movement of the pilot from right to left position
The graph represents the trajectory of the nose.
The EMG of this movement is highlighted in yellow.





Movement of the pilot from left to up position.
The graph represents the trajectory of the nose.
The EMG of this movement is highlighted in yellow.

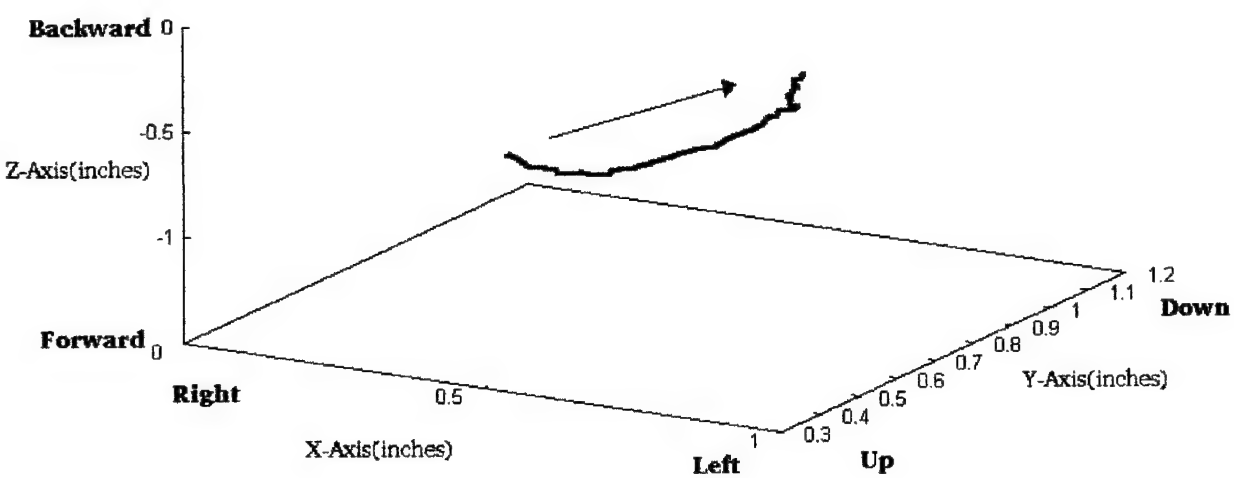


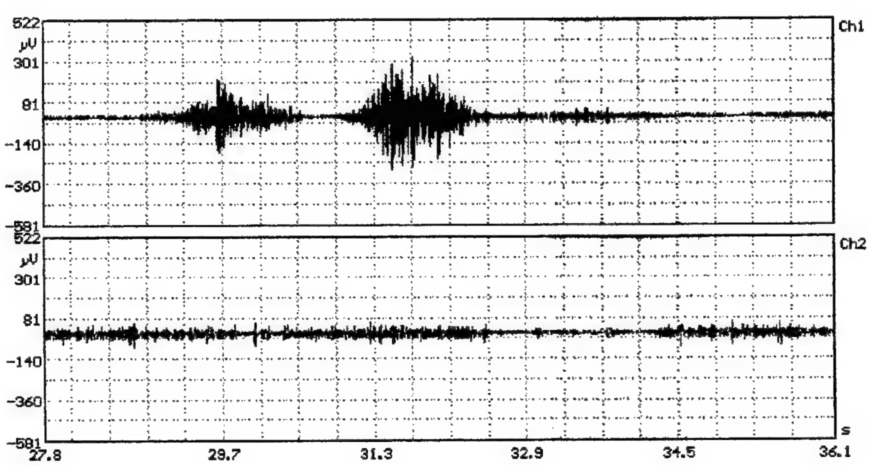


Movement of the pilot from up to down position.

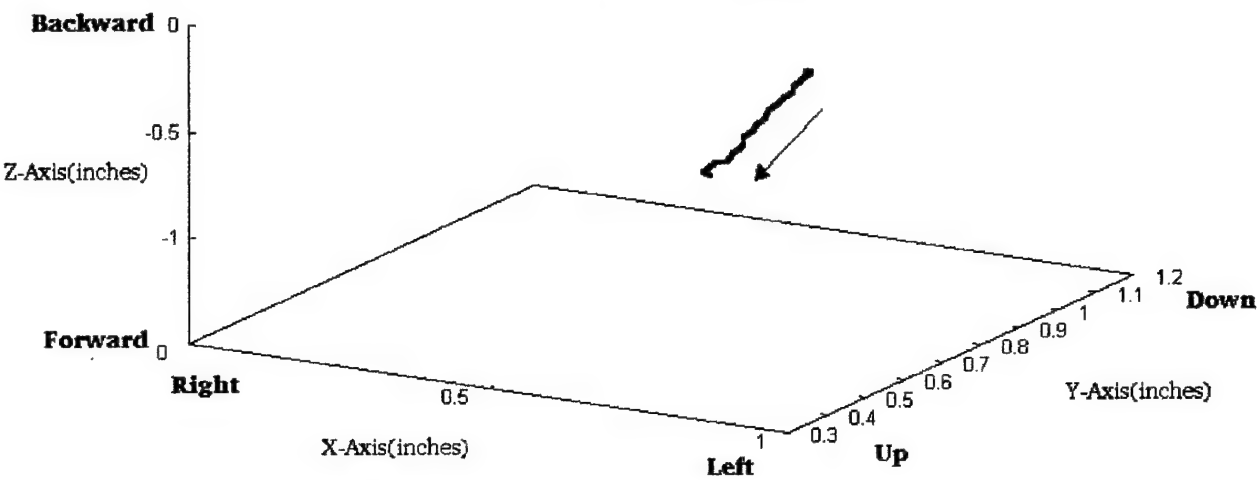
The graph represents the trajectory of the nose.

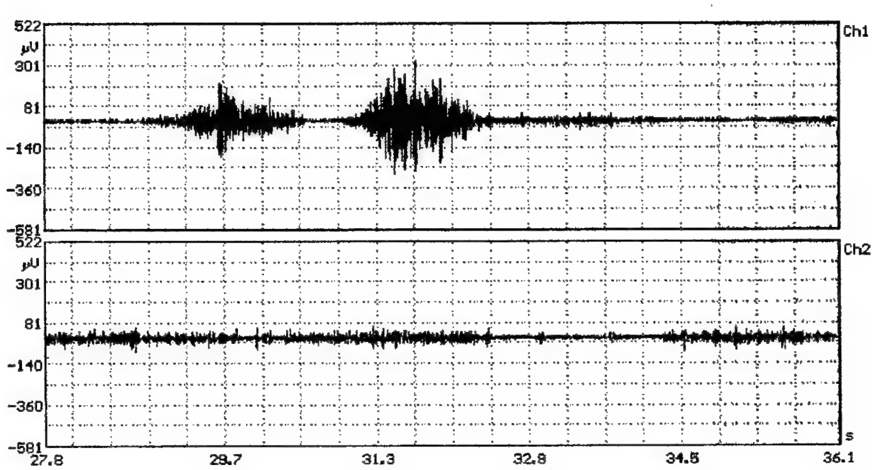
The EMG of this movement is highlighted in yellow.



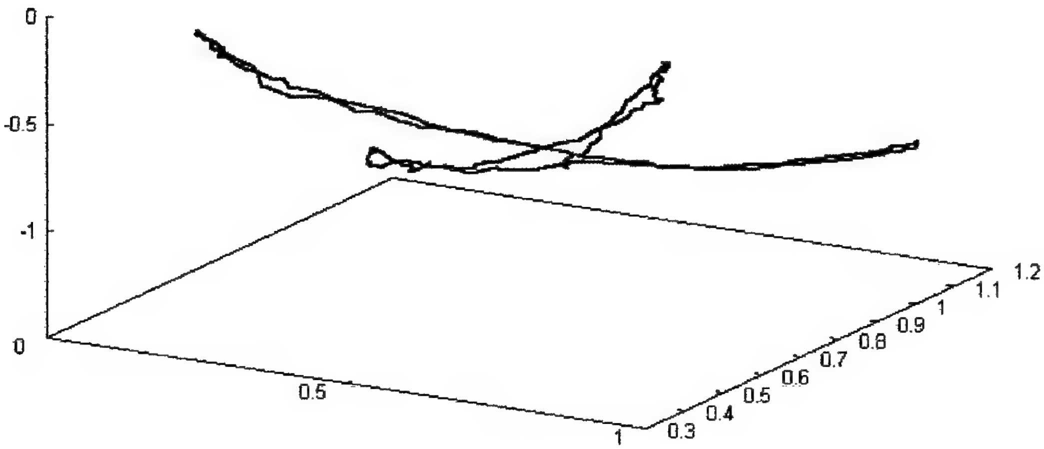


Movement of the pilot from down to neutral position.
The graph represents the trajectory of the nose.
The EMG of this movement is highlighted in yellow.

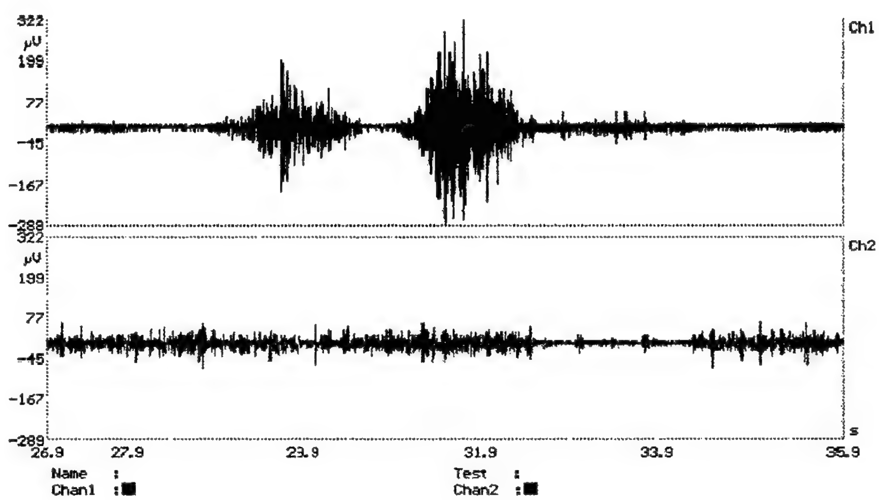




Complete movement of the pilot from Neutral, Right, Down, Up, Down position.



EMG of the Pilot's Movement.



APPENDIX C

FT. RUCKER EMG DATA

PHASIC BURST OF THE LUMBAR 4-5 ASSOCIATED WITH <u>RIGHT</u> HEAD MOVEMENT
(RUCKER)

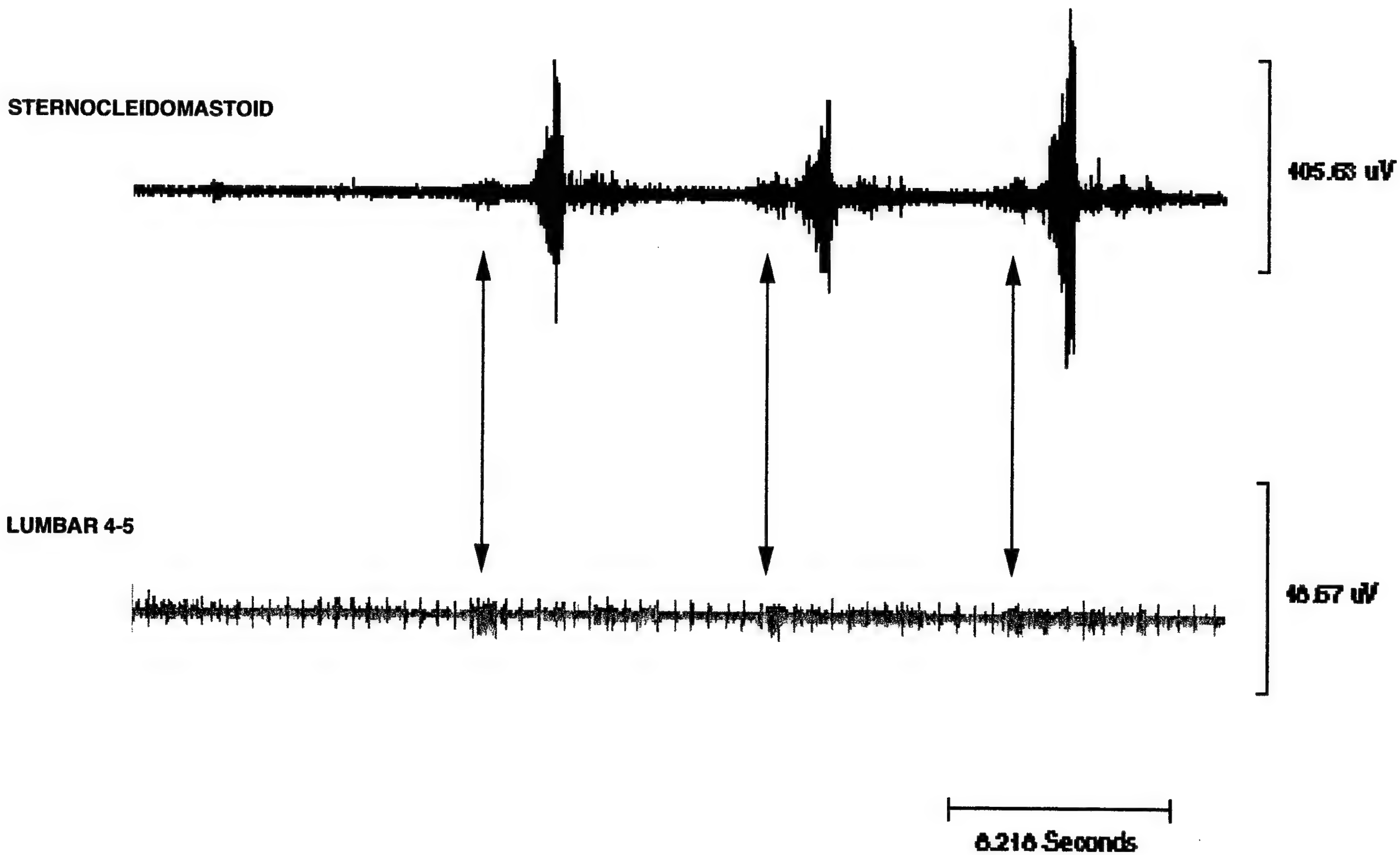
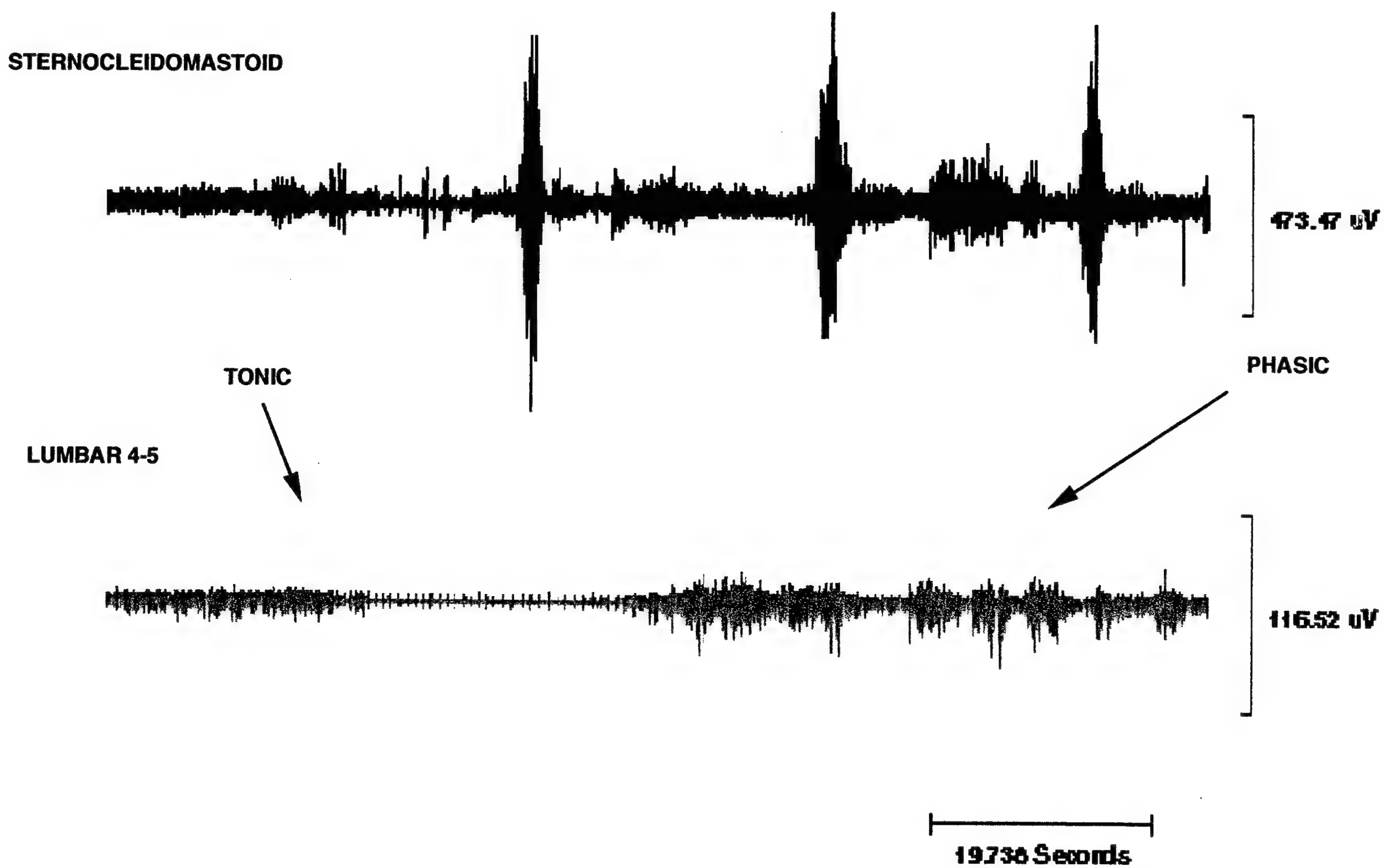


ILLUSTRATION OF BOTH <u>TONIC</u> AND <u>PHASIC</u> ACTIVITY OF THE LUMBAR 4-5 ASSOCIATED WITH HEAD MOVEMENT

(RUCKER)



APPENDIX D

EMG DATA COLLECTED PRE-AND POSTFLIGHT

EMG DATA COLLECTED PRE- AND POSTFLIGHT.

Back EMG RMS Amplitude (μvolts)

Subject #	Time 1: Preflight, rotors off	Time 2: Preflight, rotors on	Time 6: Postflight, rotors on	Time 7: Postflight rotors off
1 (m)	20.20	0.64	3.20	0.95
2 (m)	1.13	2.07	1.94	1.32
3 (m)	1.65	1.70	4.76	4.79
4 (f)	2.28	5.82	5.94	3.91
5 (f)	1.05	0.48	1.68	1.88
6 (m)	4.38	-	-	-
7 (m)	-	10.48	11.68	14.10
8 (m)	-	12.62	-	-
9 (m)	1.22	1.40	3.00	2.35
10 (f)	6.35	-	9.38	-

Neck EMG Median Power Frequency (Hz)

Subject #	Time 1: Preflight, rotors off	Time 2: Preflight, rotors on	Time 6: Postflight, rotors on	Time 7: Postflight rotors off
1 (m)	21.8	23.5	15.9	16.0
2 (m)	13.9	13.1	11.2	13.8
3 (m)	17.5	12.8	14.9	10.9
4 (f)	20.1	27.2	19.0	18.9
5 (f)	16.0	13.1	18.8	9.17
6 (m)	21.3	-	-	-
7 (m)	-	19.0	15.8	16.2
8 (m)	-	13.3	-	-
9 (m)	18.3	21.6	14.6	16.2
10 (f)	16.8	-	21.1	-

Neck EMG RMS Amplitude (μvolts)

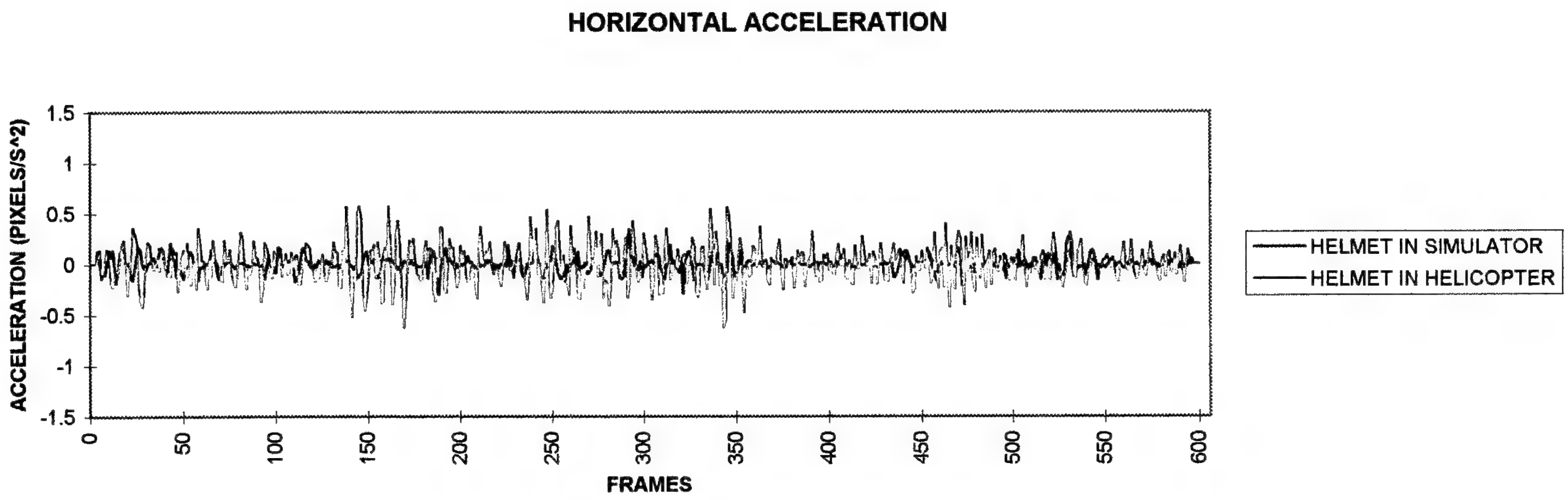
Subject #	Time 1: Preflight, rotors off	Time 2: Preflight, rotors on	Time 6: Postflight, rotors on	Time 7: Postflight rotors off
1 (m)	25.5	21.9	20.4	25.5
2 (m)	43.8	51.3	36.4	34.3
3 (m)	17.2	16.5	32.8	26.0
4 (f)	8.2	3.6	12.2	11.2
5 (f)	35.8	34.1	23.4	7.7
6 (m)	31.9	-	-	-
7 (m)	-	32.3	26.9	37.3
8 (m)	-	46.1	-	-
9 (m)	18.1	26.7	31.6	-
10 (f)	8.7	-	16.5	-

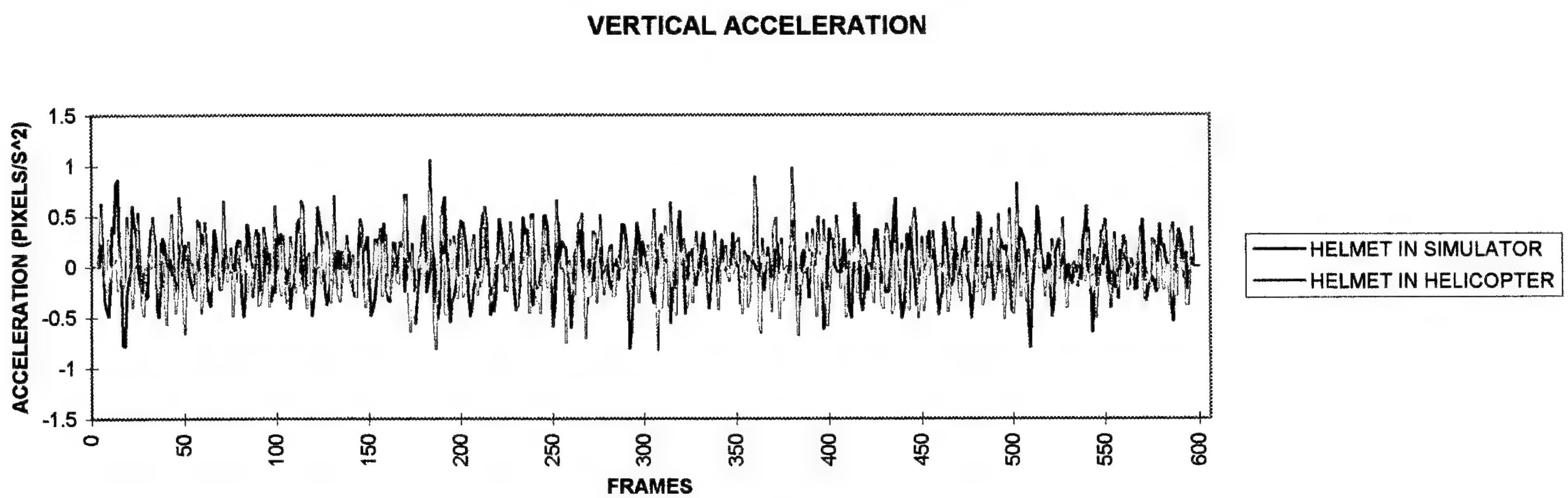
Back EMG Median Power Frequency (Hz)

Subject #	Time 1: Preflight, rotors off	Time 2: Preflight, rotors on	Time 6: Postflight, rotors on	Time 7: Postflight rotors off
1 (m)	16.9	28.7	25.3	17.4
2 (m)	15.7	19.6	19.7	15.4
3 (m)	16.1	14.1	17.6	15.7
4 (f)	20.4	15.9	29.2	13.3
5 (f)	30.1	17.8	31.8	25.4
6 (m)	15.4	-	-	-
7 (m)	-	33.1	19.1	21.8
8 (m)	-	15.8	-	-
9 (m)	14.2	14.9	20.16	21.1
10 (f)	20.6	-	18.8	-

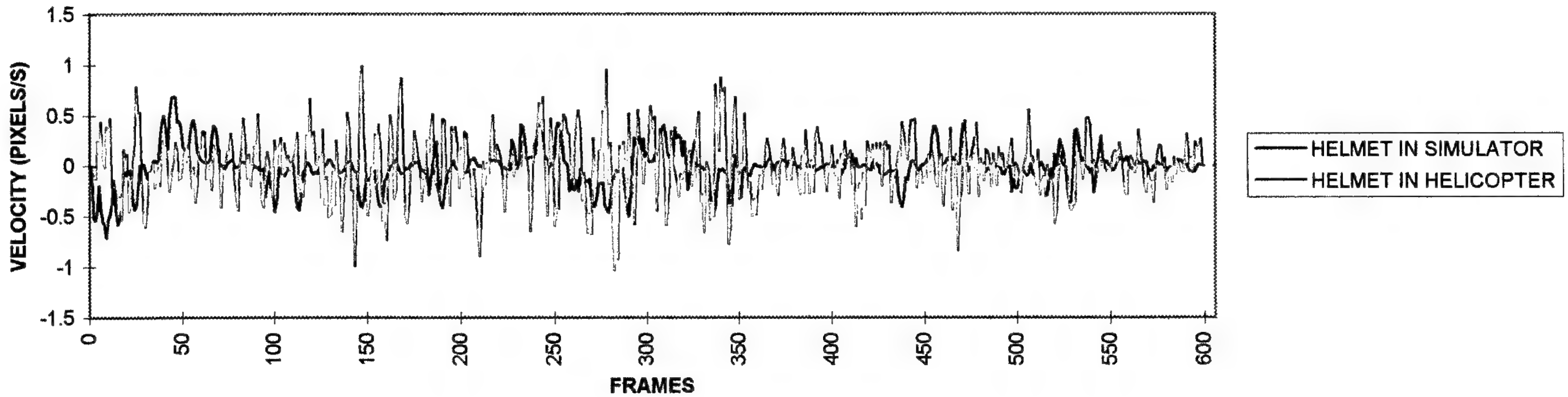
APPENDIX E

FT. RUCKER MARS PROFILES

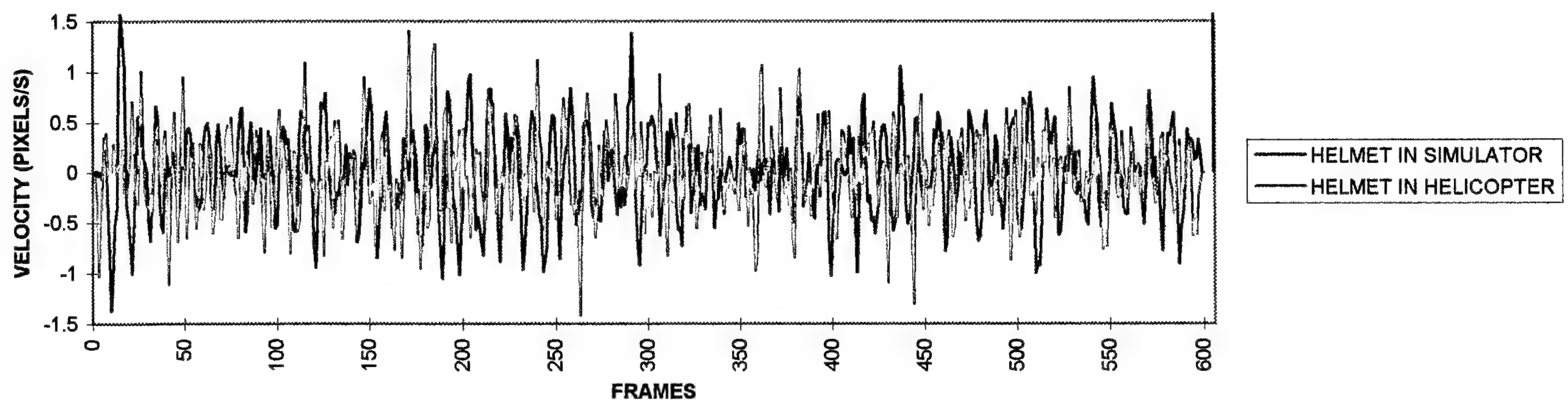

HORIZONTAL ACCELERATION
ACCELERATION (PIXELS/S^2)
1.5
1
0.5
0
-0.5
-1
-1.5
0
50
100
150
200
250
300
350
400
450
500
550
600
FRAMES
HELMET IN SIMULATOR
HELMET IN HELICOPTER

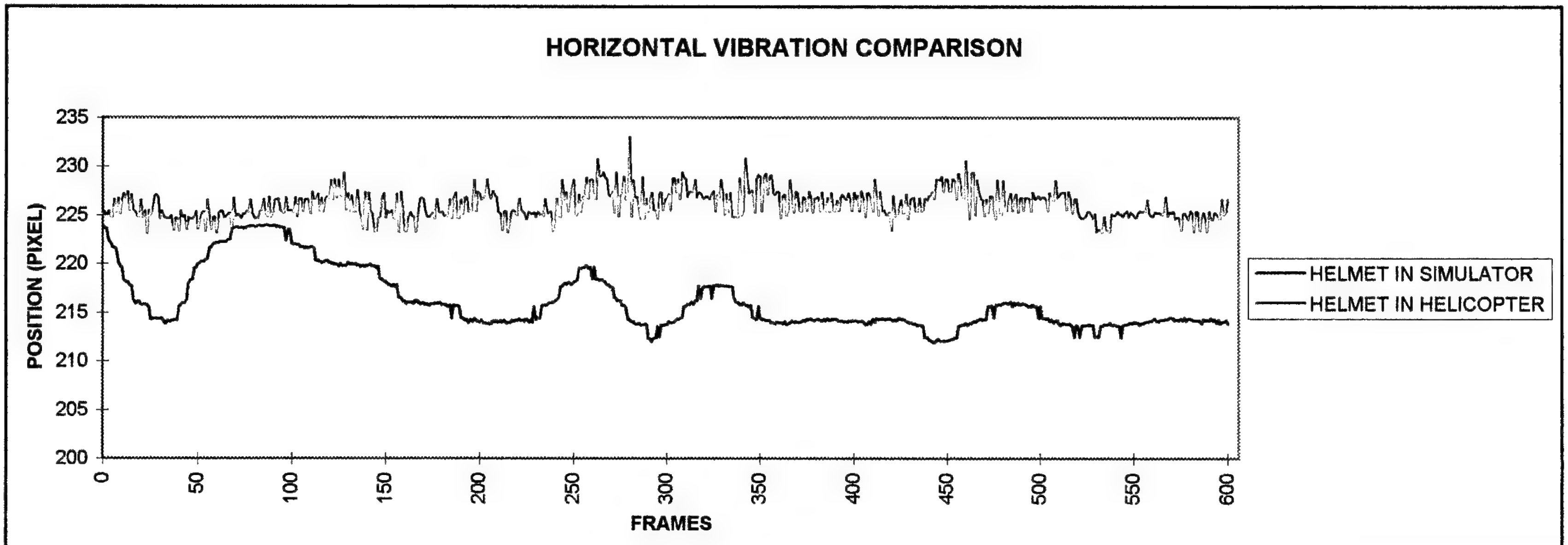

VERTICAL ACCELERATION
ACCELERATION (PIXELS/S^2)
1.5
1
0.5
0
-0.5
-1
-1.5
0
50
100
150
200
250
300
350
400
450
500
550
600
FRAMES
HELMET IN SIMULATOR
HELMET IN HELICOPTER

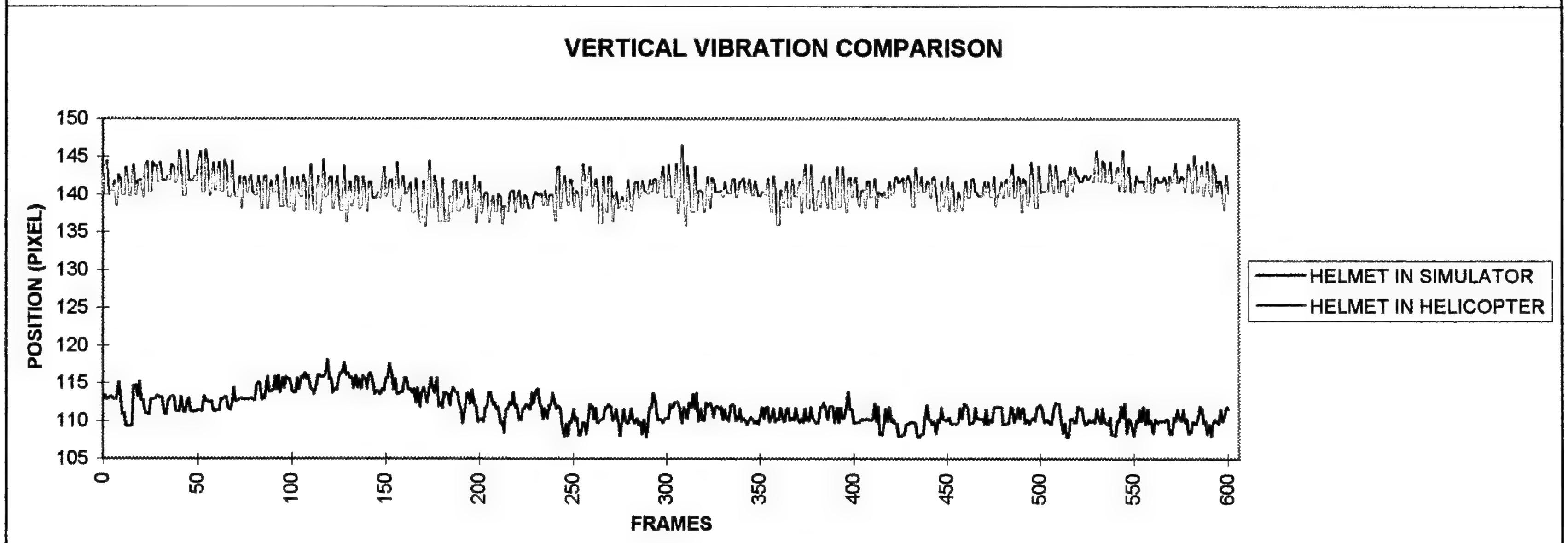
HORIZONTAL VELOCITY



VERTICAL VELOCITY

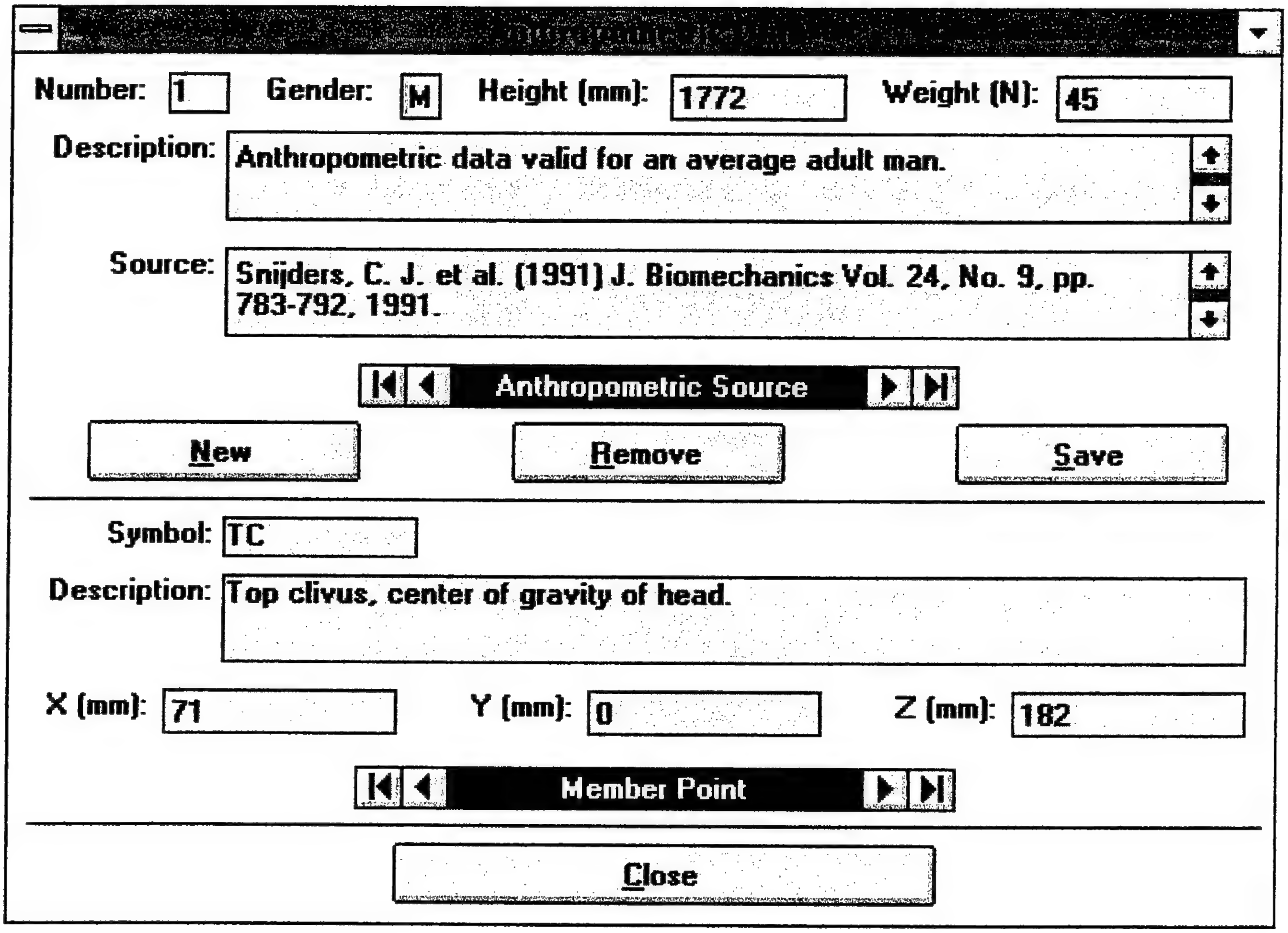


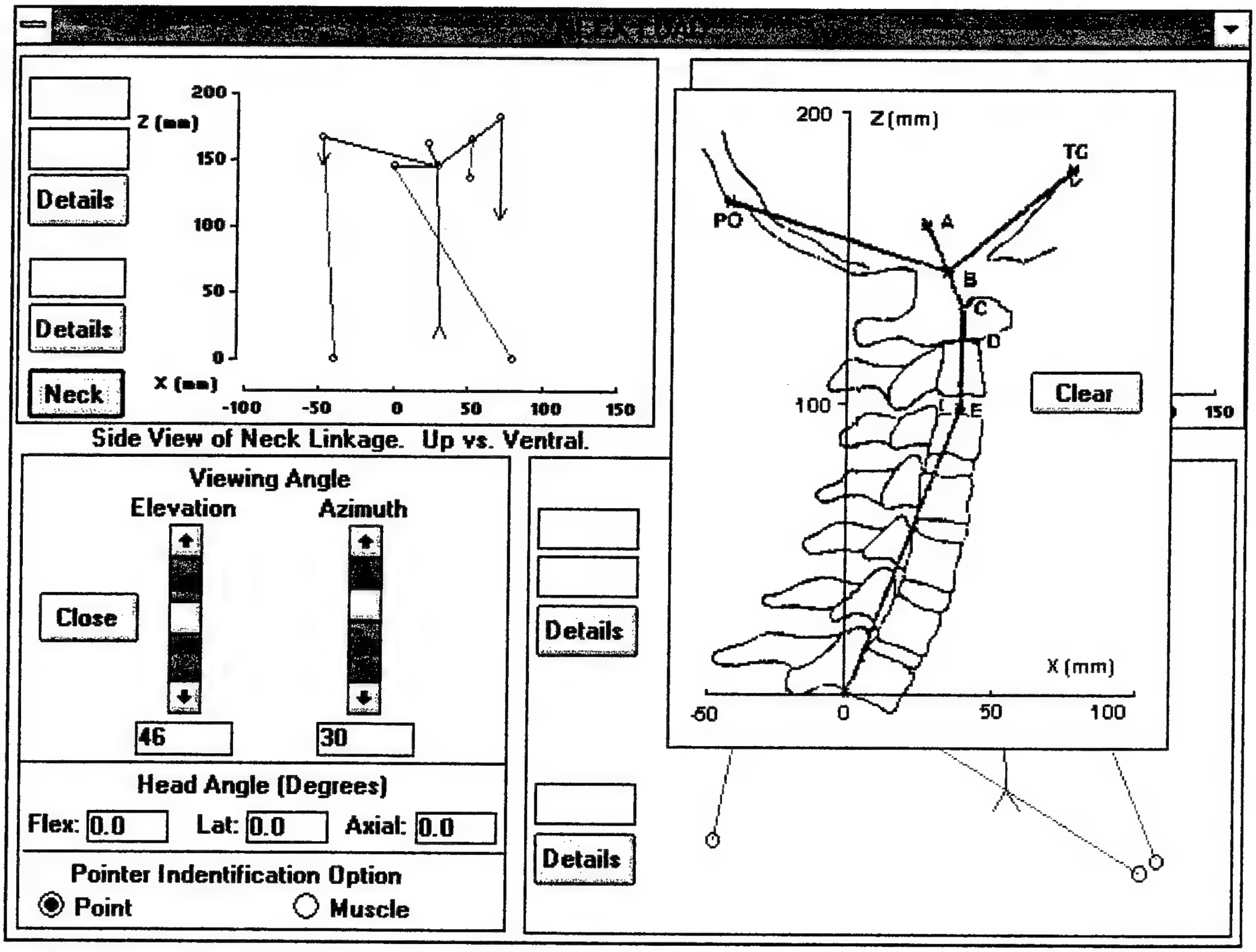

HORIZONTAL VIBRATION COMPARISON
POSITION (PIXEL)
235
230
225
220
215
210
205
200
0
50
100
150
200
250
300
350
400
450
500
550
600
FRAMES
HELMET IN SIMULATOR
HELMET IN HELICOPTER

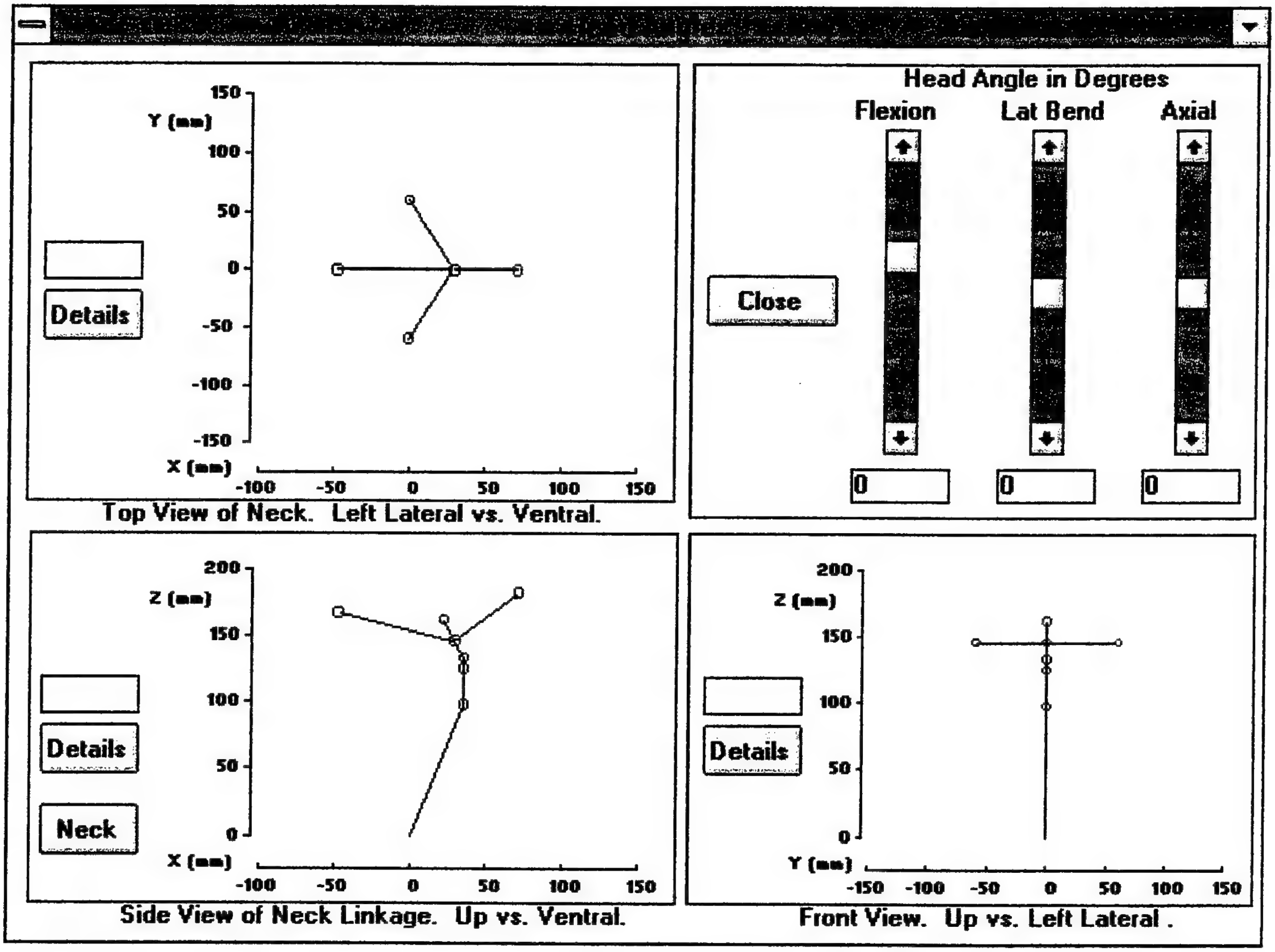

VERTICAL VIBRATION COMPARISON
POSITION (PIXEL)
150
145
140
135
130
125
120
115
110
105
0
50
100
150
200
250
300
350
400
450
500
550
600
FRAMES
HELMET IN SIMULATOR
HELMET IN HELICOPTER

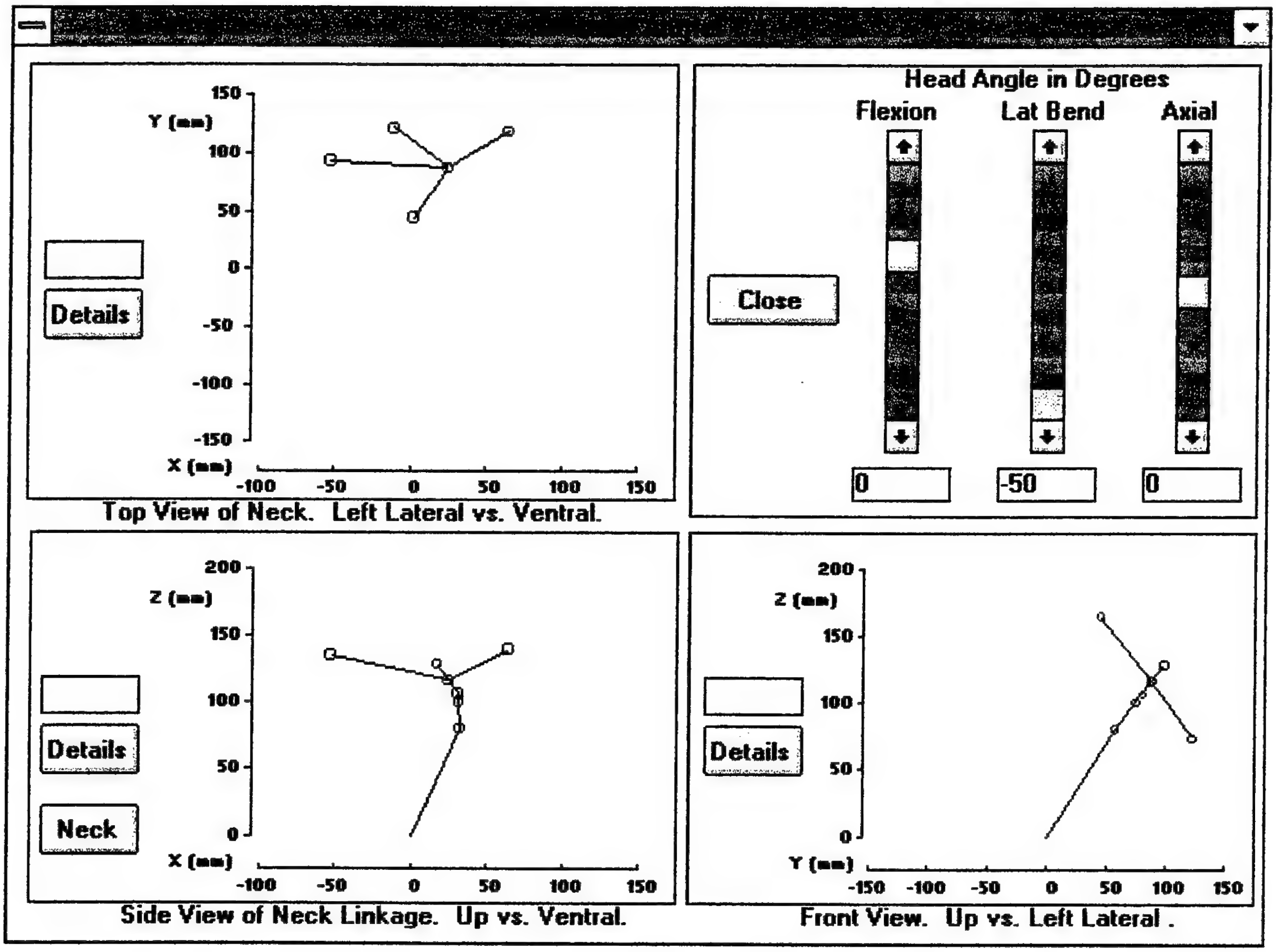
APPENDIX F

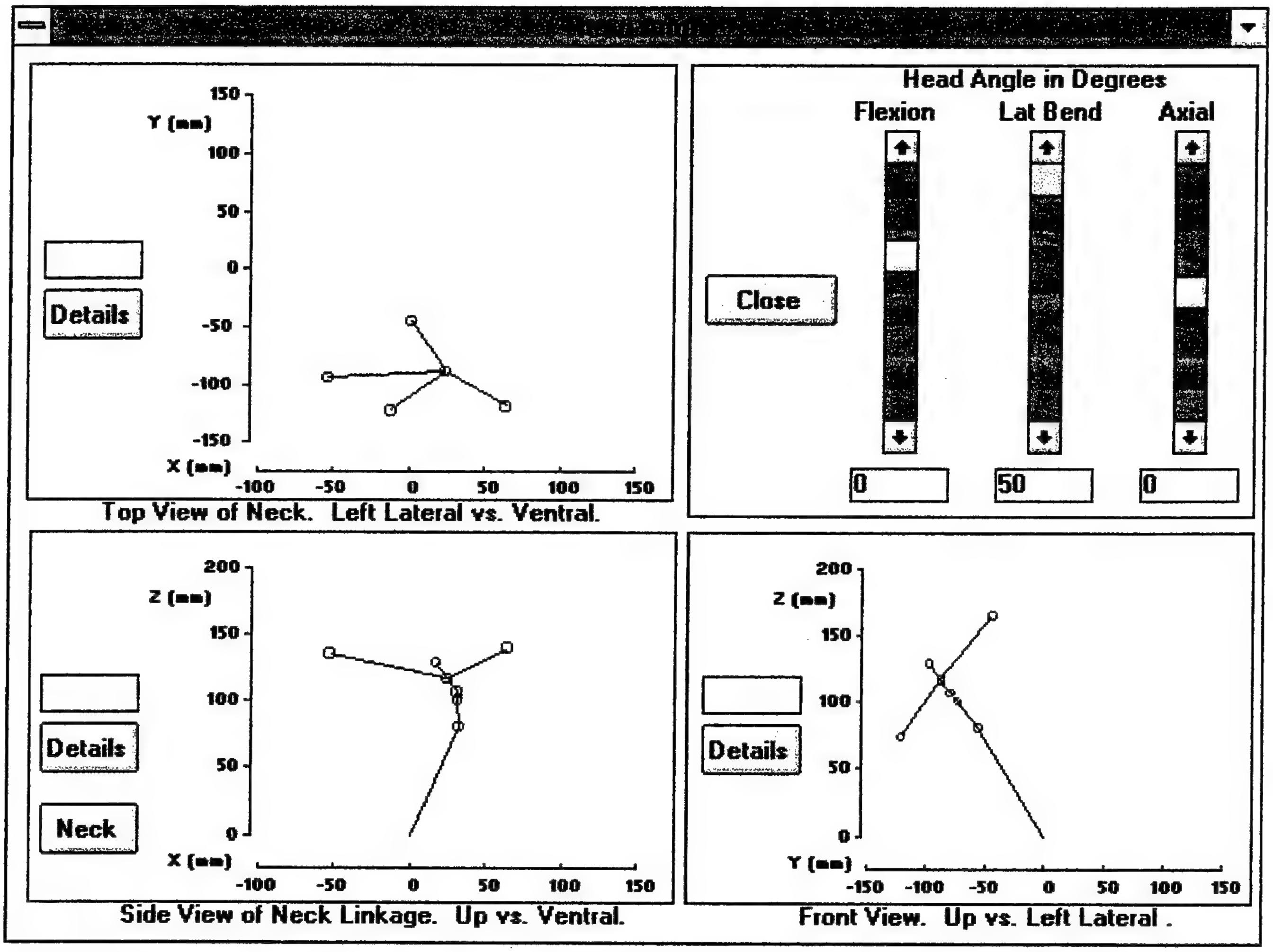
BIOMECHANICAL MODEL


Number: 1
Gender: M
Height (mm): 1772
Weight (N): 45
Description: Anthropometric data valid for an average adult man.
Source: Snijders, C. J. et al. (1991) J. Biomechanics Vol. 24, No. 9, pp. 783-792, 1991.
Anthropometric Source
New
Remove
Save
Symbol: TC
Description: Top clivus, center of gravity of head.
X (mm): 71
Y (mm): 0
Z (mm): 182
Member Point
Close

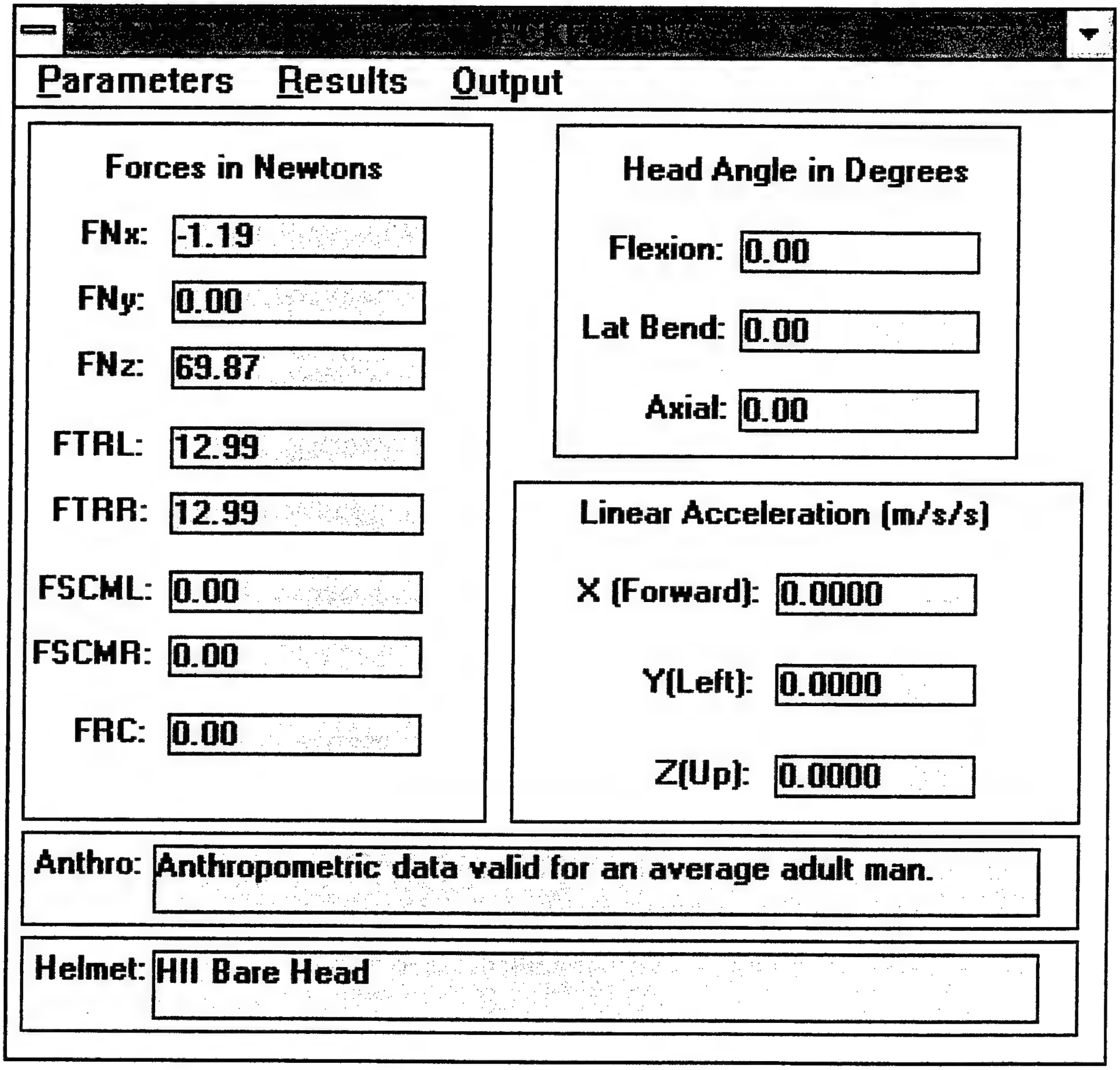

Details
Details
Neck
200
Z (mm)
150
100
50
0
X (mm)
-100
-50
0
50
100
150
Side View of Neck Linkage. Up vs. Ventral.
Viewing Angle
Elevation
Azimuth
Close
46
30
Head Angle (Degrees)
Flex: 0.0
Lat: 0.0
Axial: 0.0
Pointer Indentification Option
Point
Muscle
Details
Details
200
Z(mm)
TC
A
PO
B
C
D
100
E
Clear
X (mm)
-50
0
50
100

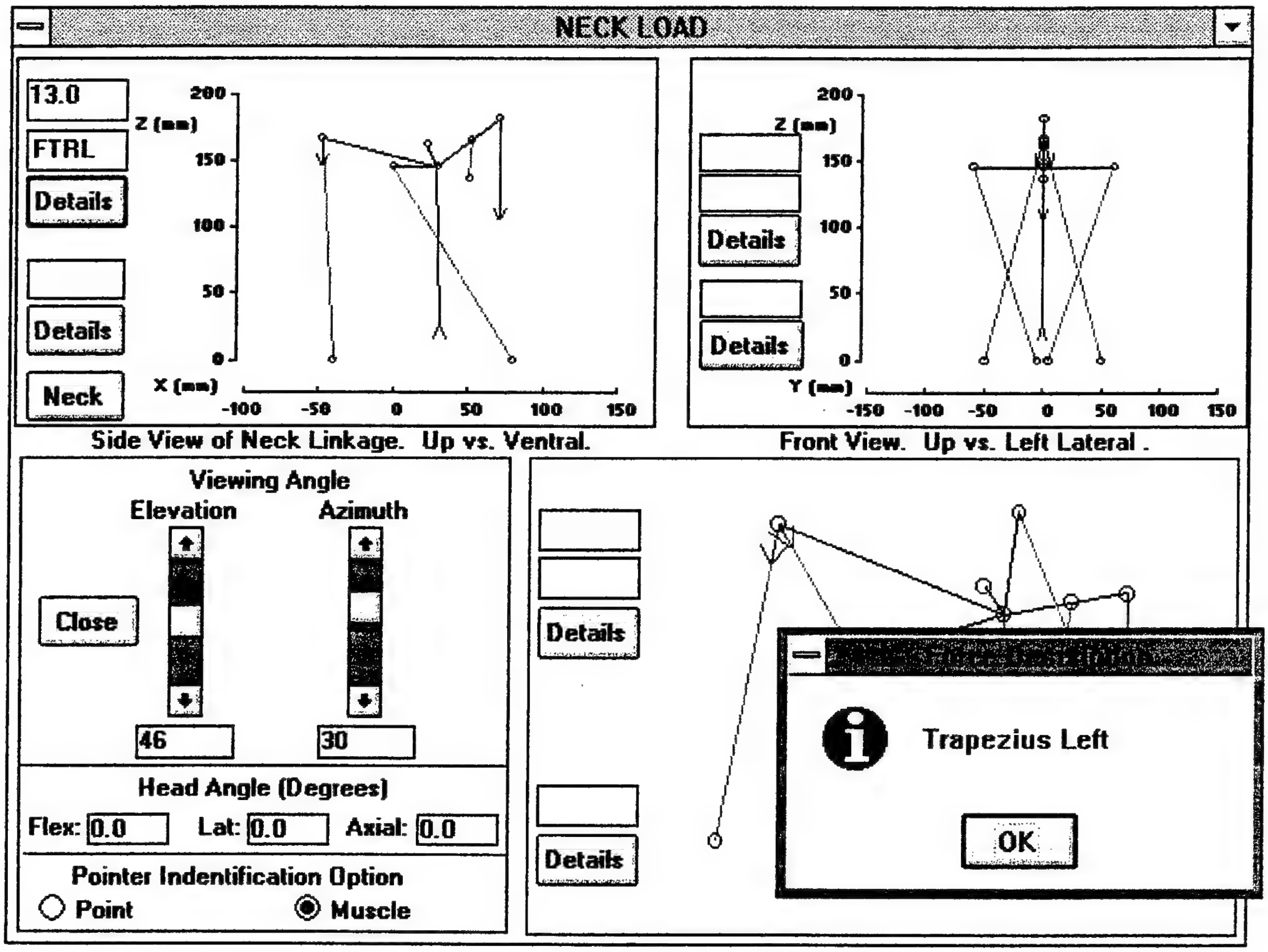

Head Angle in Degrees
Flexion
Lat Bend
Axial
Close
Details
Neck
Y (mm)
X (mm)
Z (mm)
150
100
50
0
-50
-100
-150
200
Top View of Neck. Left Lateral vs. Ventral.
Side View of Neck Linkage. Up vs. Ventral.
Front View. Up vs. Left Lateral .

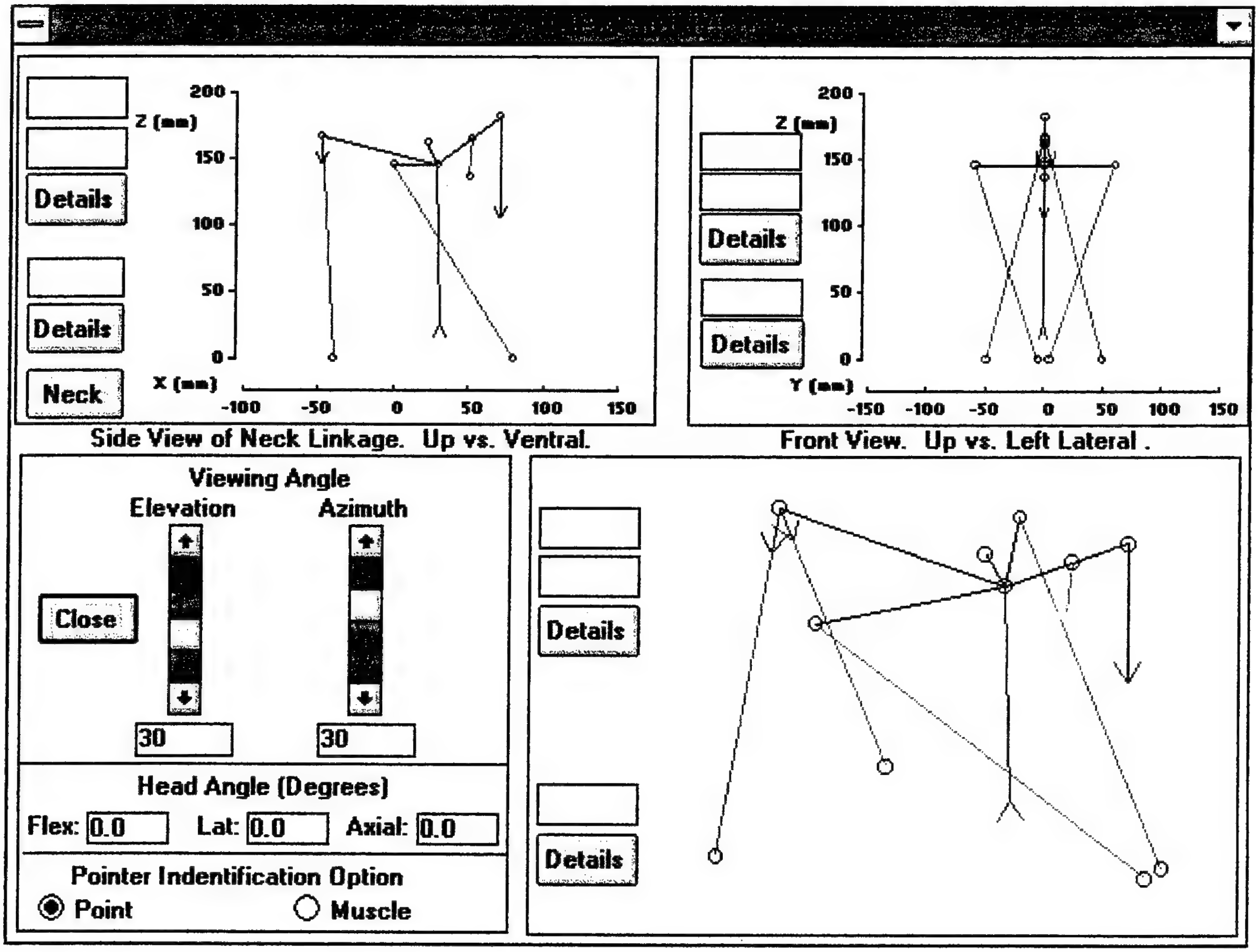

Head Angle in Degrees
Flexion
Lat Bend
Axial
Close
0
-50
0
Details
Details
Neck
Details
Y (mm)
X (mm)
Z (mm)
150
100
50
0
-50
-100
-150
200
Top View of Neck. Left Lateral vs. Ventral.
Side View of Neck Linkage. Up vs. Ventral.
Front View. Up vs. Left Lateral .

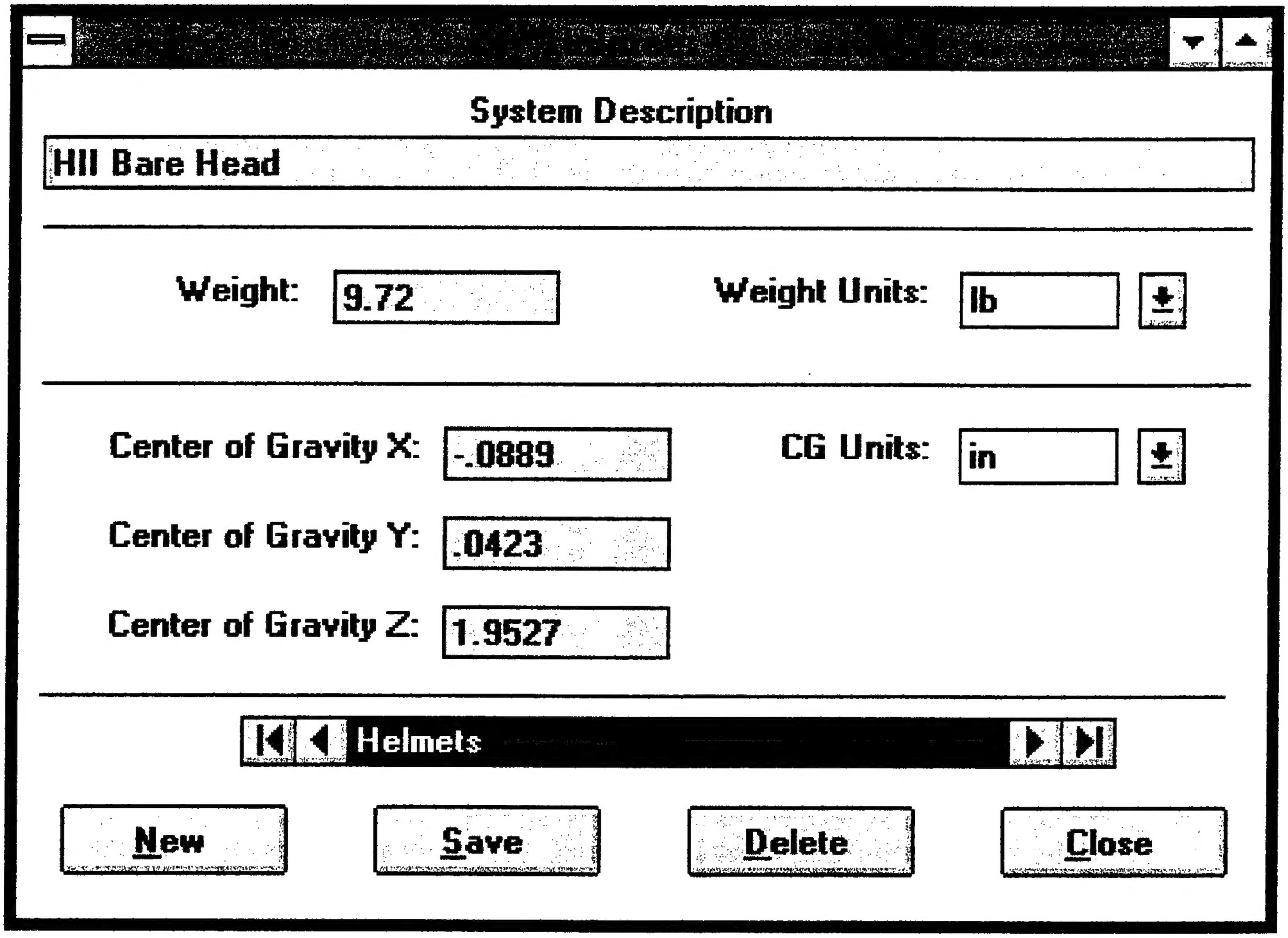


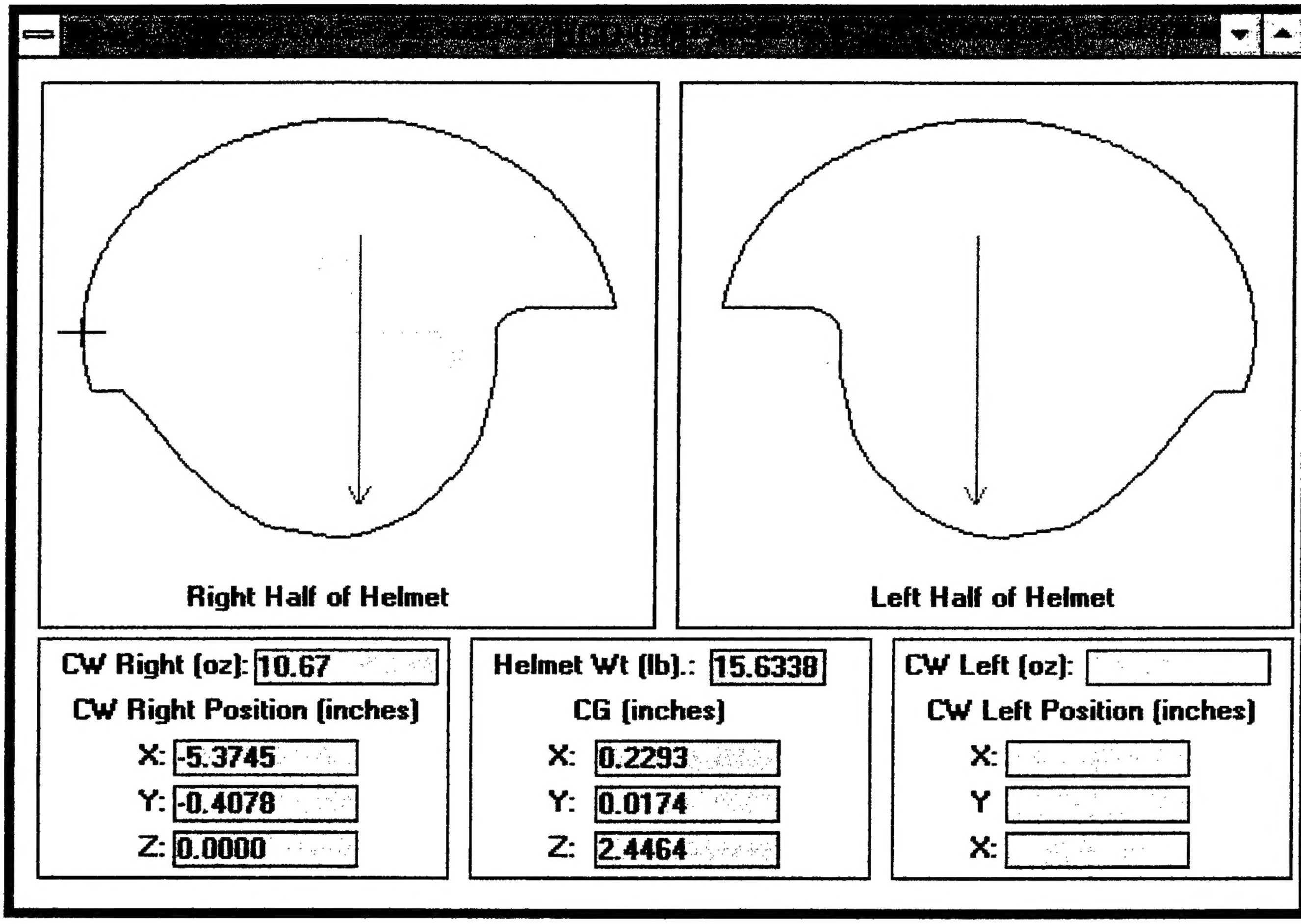
Head Angle in Degrees
Flexion
Lat Bend
Axial
Close
0
50
0
Details
Details
Neck
Details
Y (mm)
X (mm)
Z (mm)
Z (mm)
Y (mm)
150
100
50
0
-50
-100
-150
-100 -50 0 50 100 150
200
Top View of Neck. Left Lateral vs. Ventral.
Side View of Neck Linkage. Up vs. Ventral.
Front View. Up vs. Left Lateral .


Parameters
Results
Output
Forces in Newtons
FNx: -1.19
FNy: 0.00
FNz: 69.87
FTRL: 12.99
FTRR: 12.99
FSCML: 0.00
FSCMR: 0.00
FRC: 0.00
Head Angle in Degrees
Flexion: 0.00
Lat Bend: 0.00
Axial: 0.00
Linear Acceleration (m/s/s)
X (Forward): 0.0000
Y(Left): 0.0000
Z(Up): 0.0000
Anthro: Anthropometric data valid for an average adult man.
Helmet: HII Bare Head


NECK LOAD
13.0
FTRL
Details
Details
Neck
200
Z (mm)
150
100
50
0
X (mm)
-100
-50
0
50
100
150
Side View of Neck Linkage. Up vs. Ventral.
Details
Details
Y (mm)
-150
-100
Front View. Up vs. Left Lateral .
Viewing Angle
Elevation
Azimuth
Close
46
30
Head Angle (Degrees)
Flex: 0.0
Lat: 0.0
Axial: 0.0
Pointer Indentification Option
Point
Muscle
Details
Details
Trapezius Left
OK


Details
Details
Neck
200
Z (mm)
150
100
50
0
X (mm)
-100 -50 0 50 100 150
Side View of Neck Linkage. Up vs. Ventral.
Details
Details
Y (mm)
-150 -100 -50 0 50 100 150
Front View. Up vs. Left Lateral .
Viewing Angle
Elevation
Azimuth
Close
30
30
Head Angle (Degrees)
Flex: 0.0
Lat: 0.0
Axial: 0.0
Pointer Indentification Option
Point
Muscle
Details
Details


System Description
HII Bare Head
Weight:
9.72
Weight Units:
lb
Center of Gravity X:
-.0889
CG Units:
in
Center of Gravity Y:
.0423
Center of Gravity Z:
1.9527
Helmets
New
Save
Delete
Close


Right Half of Helmet
Left Half of Helmet
CW Right (oz): 10.67
CW Right Position (inches)
X: -5.3745
Y: -0.4078
Z: 0.0000
Helmet Wt (lb).: 15.6338
CG (inches)
X: 0.2293
Y: 0.0174
Z: 2.4464
CW Left (oz):
CW Left Position (inches)
X:
Y
X:

APPENDIX G

MEETING ABSTRACTS, TECHNICAL REPORTS, PATENTS, PERSONNEL

MEETINGS ABSTRACTS, TR'S, PATENTS, PERSONNEL

Feith, S.J., Czaplinski, B.A., Couris, M.T., Pozos, R.S., & Mooney, V. (1996). Neck strength and associated neck and back EMG of female U.S. Navy helicopter pilots. Aviat Space Environ Med. 67(7): 682.

Feith, S.J., Hartsfield, J.F., Kaehr, J.W., & Pozos, R.S. (1995). Incidence of neck/back pain in aircrews of F-14 and F/A-18 aircraft. FASEB J. 9(4): 5064.

Feith, S.J., Hartsfield, J.F., Kaehr, J.W., Czaplinski, B.A., Couris, M.T., & Pozos, R.S. (1995). Incidence of neck/back pain in pilots of U.S. Navy and Marine Corps helicopters. Aviat Space Environ Med. 66(5): 506.

Couris, M.T., Held, M.H., Pozos, R.S., Feith, S.J., Karu, Z.Z., & Moore, C.D. (1994). Neck and back electromyography (EMG) during helicopter flight. Aviat Space Environ Med. 65(5): 439.

Pozos, R.S., Feith, S.J., Booth, R., & Moore, C.D. (1993). In-flight EMG measurements of neck and back muscles during sustained +Gz forces. Aviat Space Environ Med. 64(5): 455.

TECHNICAL REPORTS

Pozos, R.S., Czaplinski, B., Couris, M.T., Hartsfield, J., & Mooney, V. (1995). Evaluation of electromyographic indices of fatigue associated with repetitive lumbar isotonic flexion and extension. In review.

PATENTS

Pozos. R.S. Flexible EMG Electrode array. Granted

PERSONNEL

Robert S. Pozos, Ph.D.
CDR Steven J. Feith, MSC, USN
LT Barry S. Cohen, Ph.D., MSC, USNR
James A. Hodgdon, Ph.D.
Jershonda Hartsfield, GEO Contractor
Sue Sobanski, GEO Contractor
Stacey Stanley, SDSU Foundation
Darcy Stiles, SDSU Foundation
Eliseo Sandoval, SDSU Foundation
David Schach, SDSU Foundation